2014 Upgrades to the HWRF Modeling System

Further Enhancements to the High-Resolution HWRF

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HFIP Telecon, April 30, 2014

Priorities for Operational HWRF for 2014 hurricane season

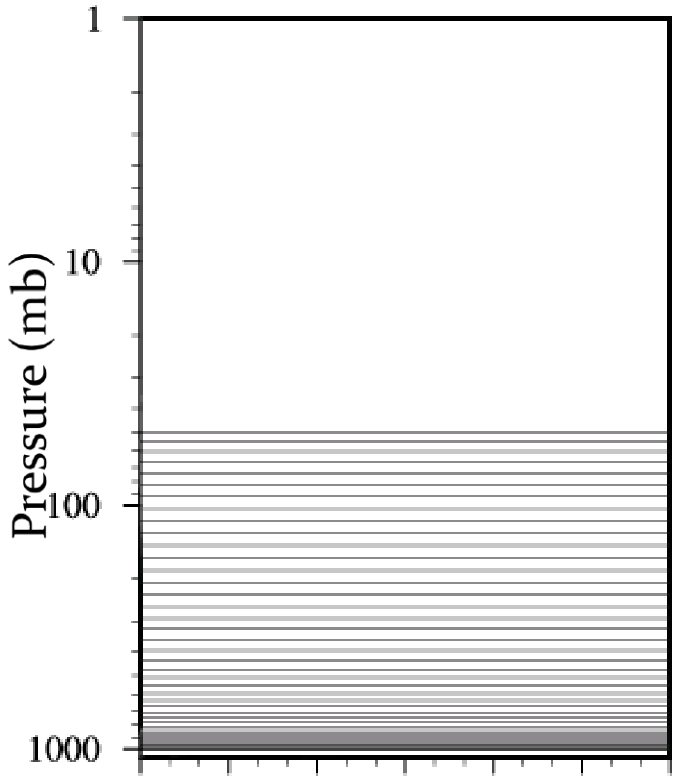
Address known problems/issues identified during the season:

a) Weak storms continued posing significant challenge
b) Moisture initialization in the model less than optimum
c) Cold start (very first cycle) cases behave different (worse) than the warm start
d) Land interactions and cold temperature bias over land
e) Smaller nest domains to contain large storms; insufficient vertical resolution for satellite DA
f) Coarse resolution of ocean model, inadequate conditions for choice of ocean domain in the Atlantic, 1-D coupling in the East Pacific

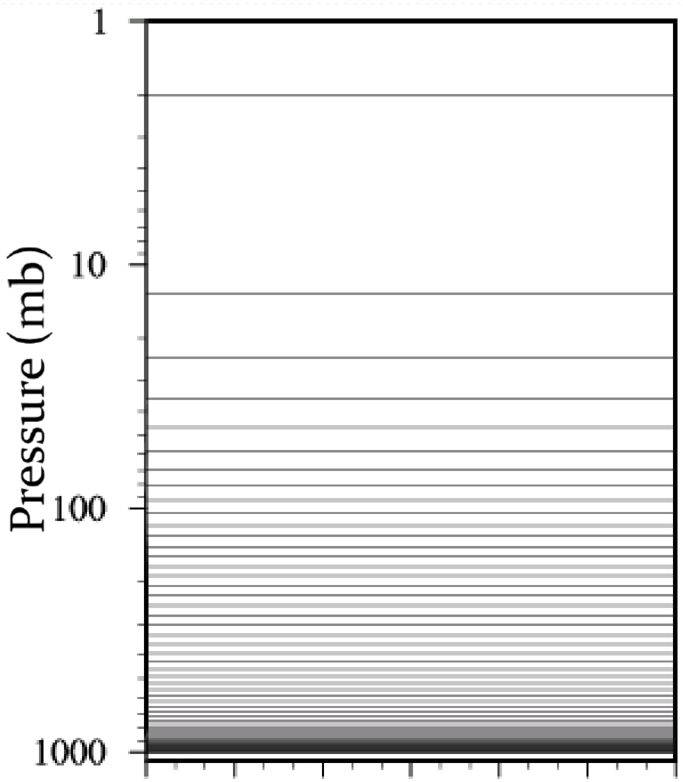
Focus areas for development, testing and evaluation

1. Increase the vertical resolution of atmospheric model to 61 levels with higher model top of 2 hPa
2. ***Upgrade HWRF physics suite to include RRTM-G, Modified Ferrier microphysics, NOAH LSM (withdrawn).***
3. Upgrade the ocean model (POM) to 1/12° MPI POM with unified trans-Atlantic basin and 3D ocean for Eastern Pacific basin. Upgrade the coupler to run on multiple processors.
4. Further improvements to HWRF vortex initialization scheme and HWRF Data Assimilation System
5. Additional operational forecast products from HWRF to include simulated brightness temperatures for new satellite sensors, several new variables for downstream applications and 6-minute ATCF output. **Special storm centric helicity & tornadic potential fields for landfalling storms at the request of SPC.**
6. **Pre-implementation tests based on proposed Q4FY13 GFS upgrades … deferred to July/August**

Increased model vertical levels (43 to 61) with higher model top (50mb to 2mb)



Operational HWRF **(43level, pt=50mb)**

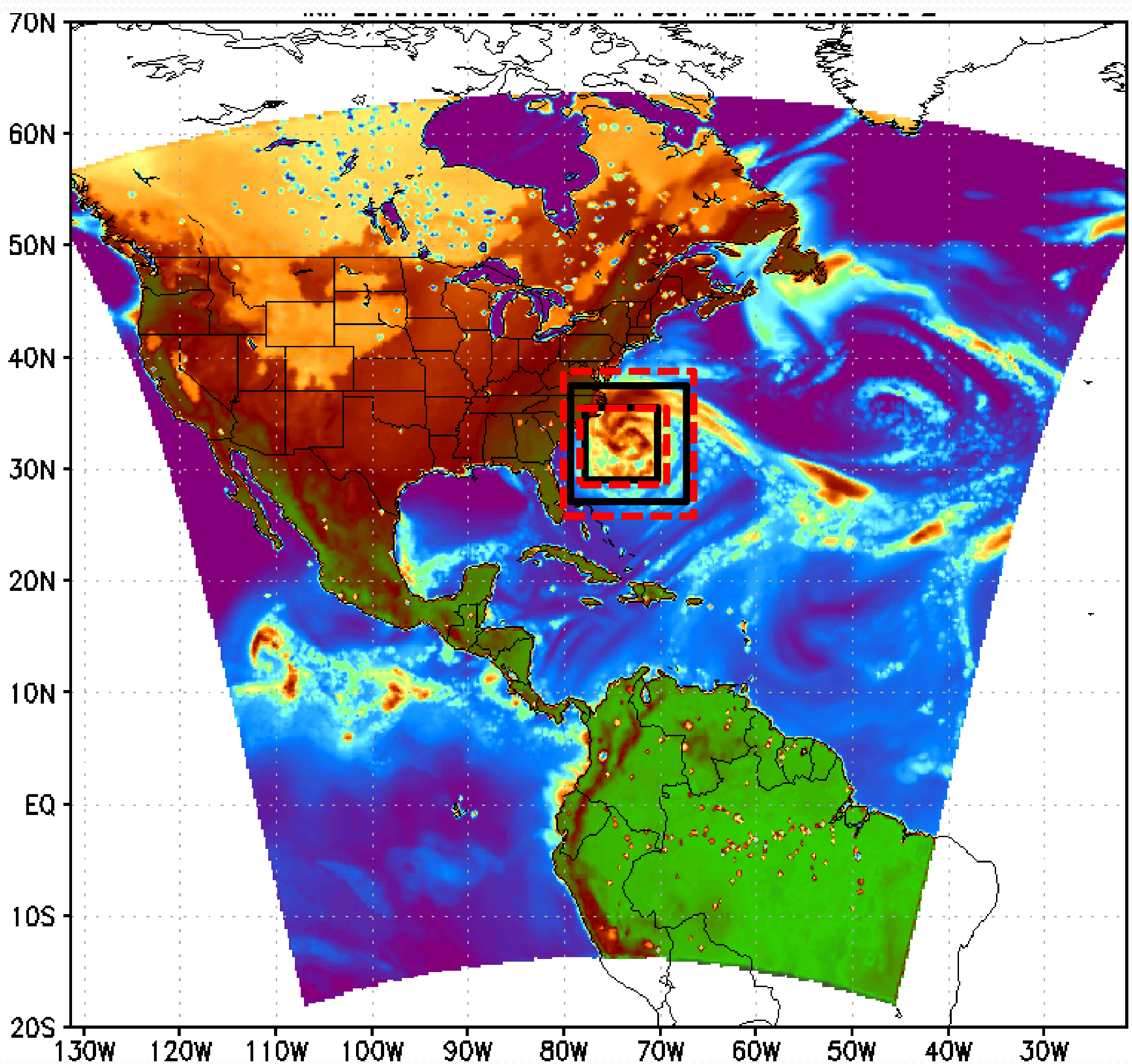


new HWRF **(61level, pt=2mb)**

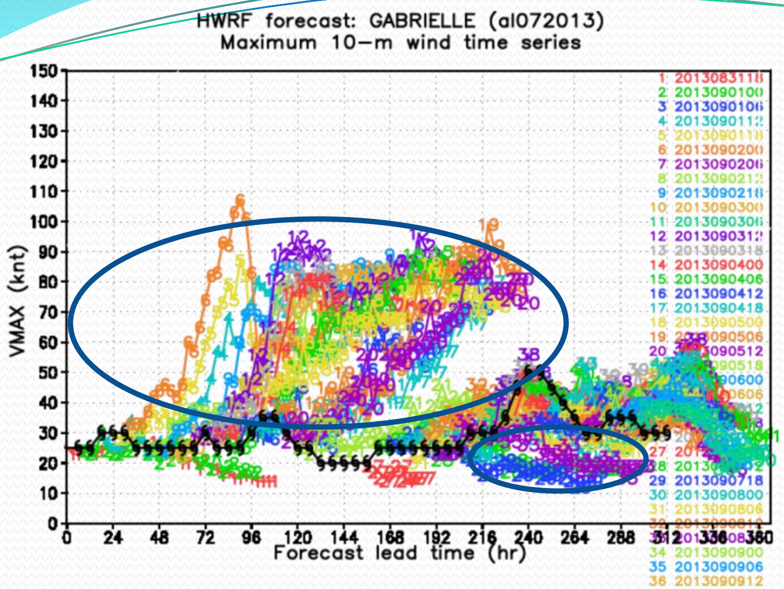
Extended nest domains
Hurricane Sandy (2012102718 +18hr fcst)

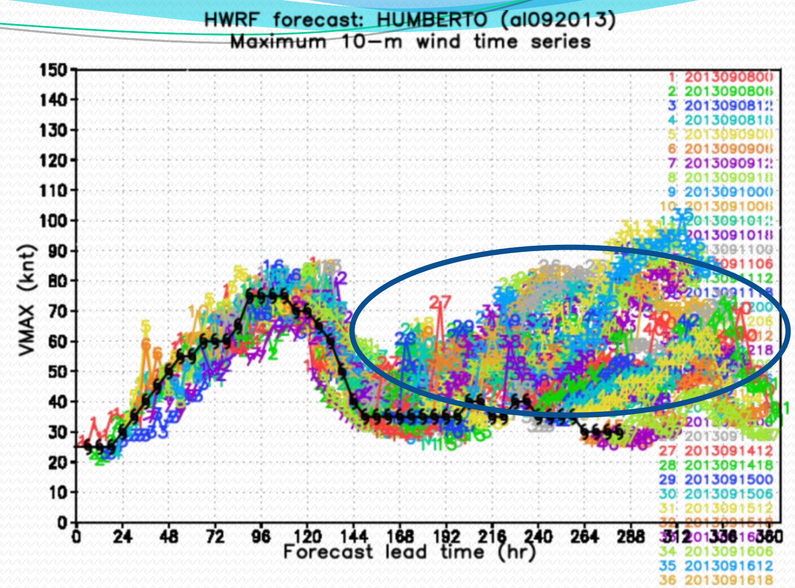
d02: 20% extended
10°X10° to 12°X12°

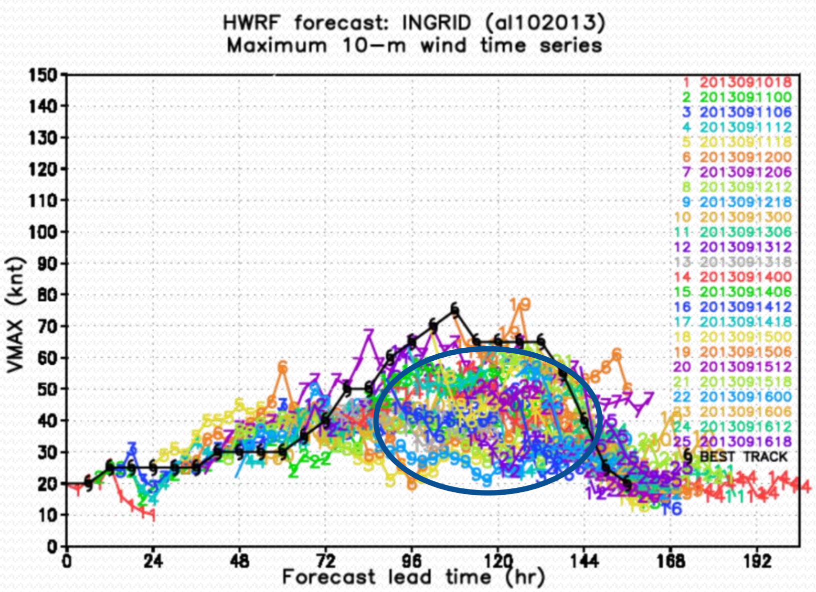
d03: 10% extended
6.5°X6.5° to 7.1°X7.1°



Problematic Storms for Intensity Forecasts





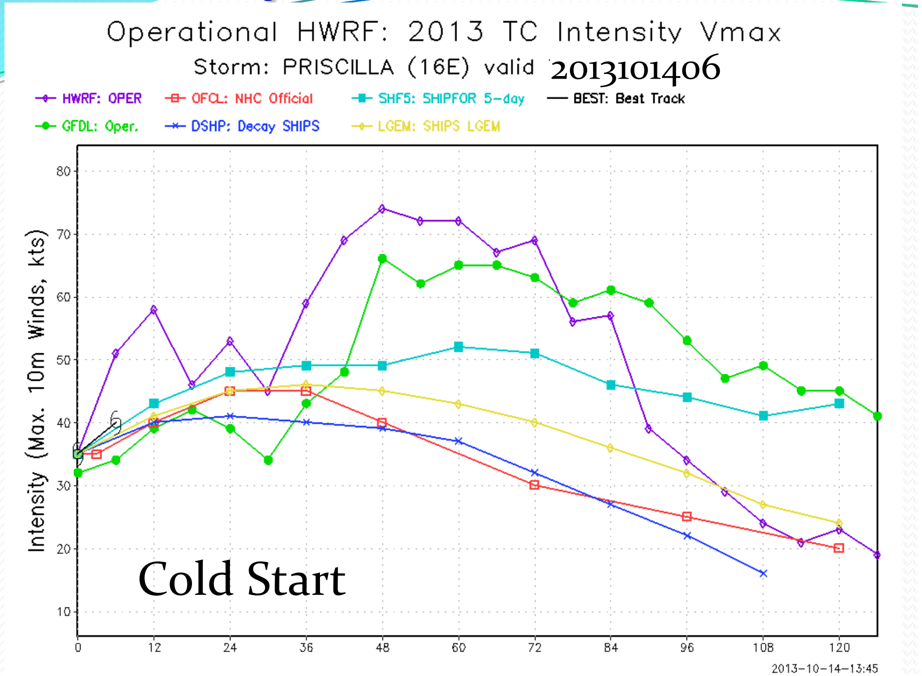


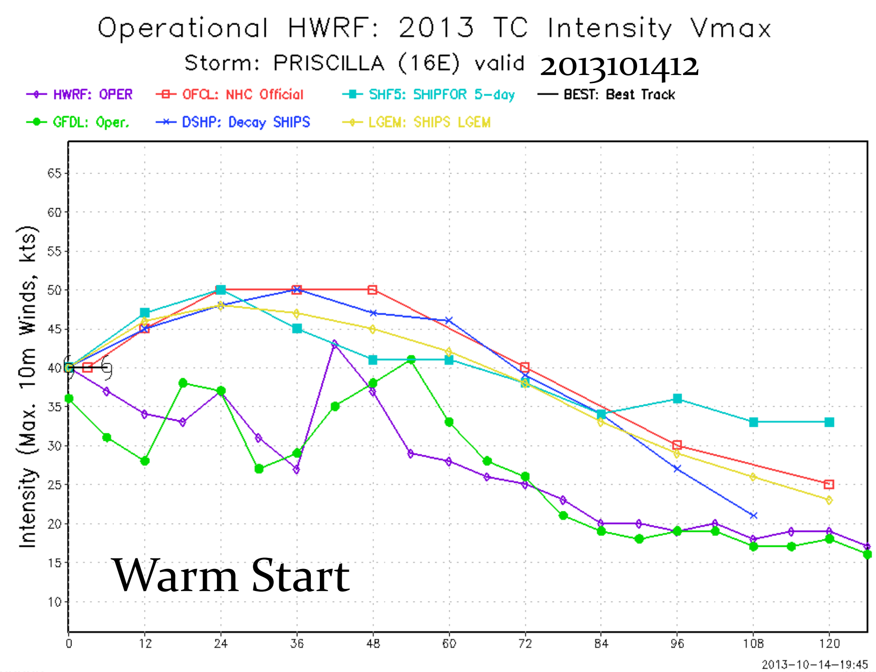
Weak storms still pose a significant challenge for HWRF.

Land interactions also impacted a few intensity forecasts for H. Ingrid

Potential initialization issues for cold start

Intensity forecasts for Cold Start



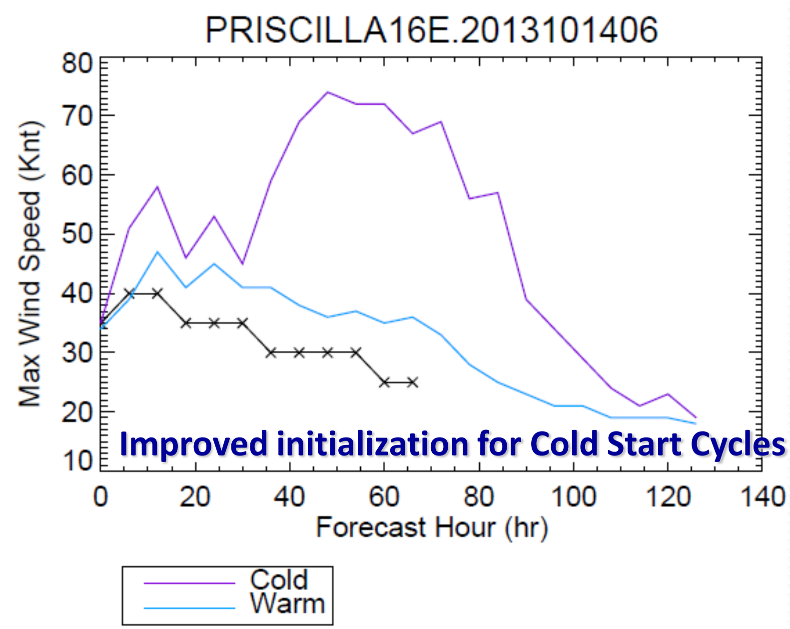


Invest 95E became Priscilla 16E on 2013101406

Cold start (bogus) intensified the storm significantly

Warm start cycles well behaved

Could we cycle the vortex from Invest 95E for first cycle of Priscilla?

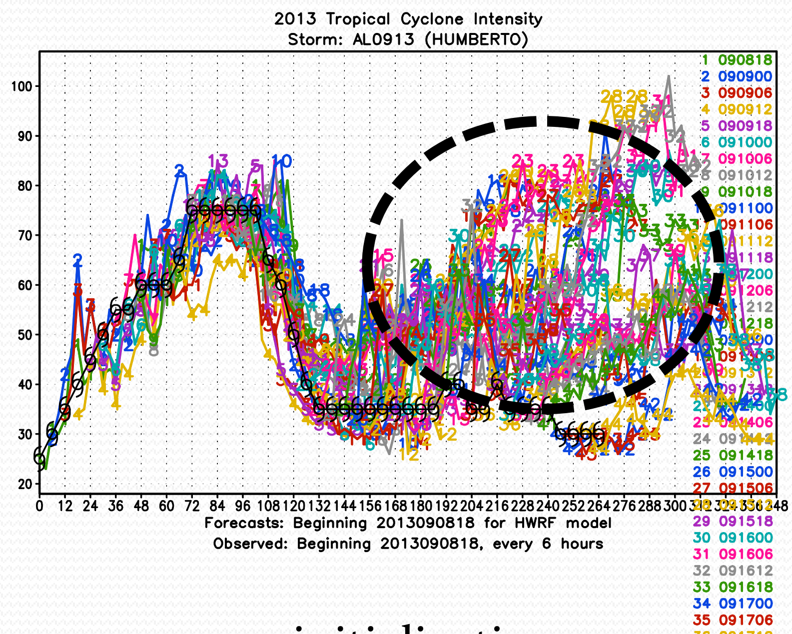


Initialization upgrades for 2014 HWRF

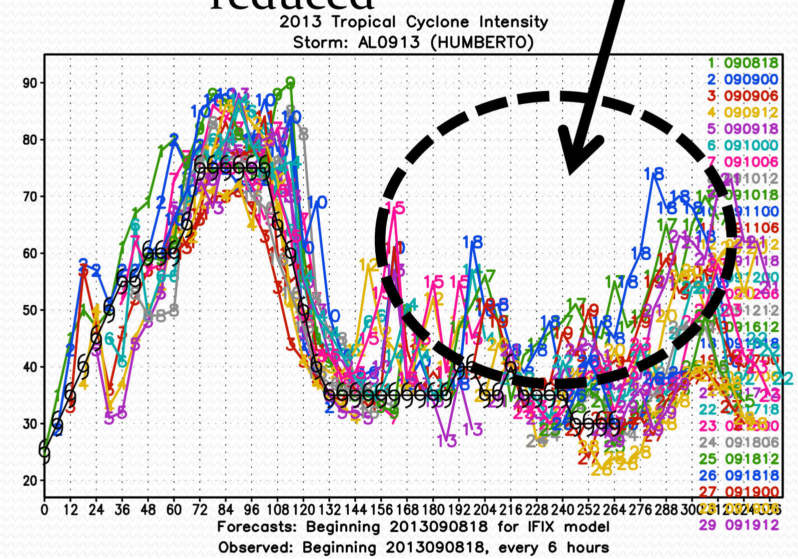
1. Match the initial maximum wind speed over the lands
2. Fix the bug of calculating south-west corner of initialization domain
3. Storm center is used in the procedure instead of using parent domain center
4. Remove the vorticity discontinuity along the filter domain
5. Avoid cold starts for the first cycle of named/numbered storm through cycling of vortex from Invest cases

Preliminary results

Strong intensity bias reduced

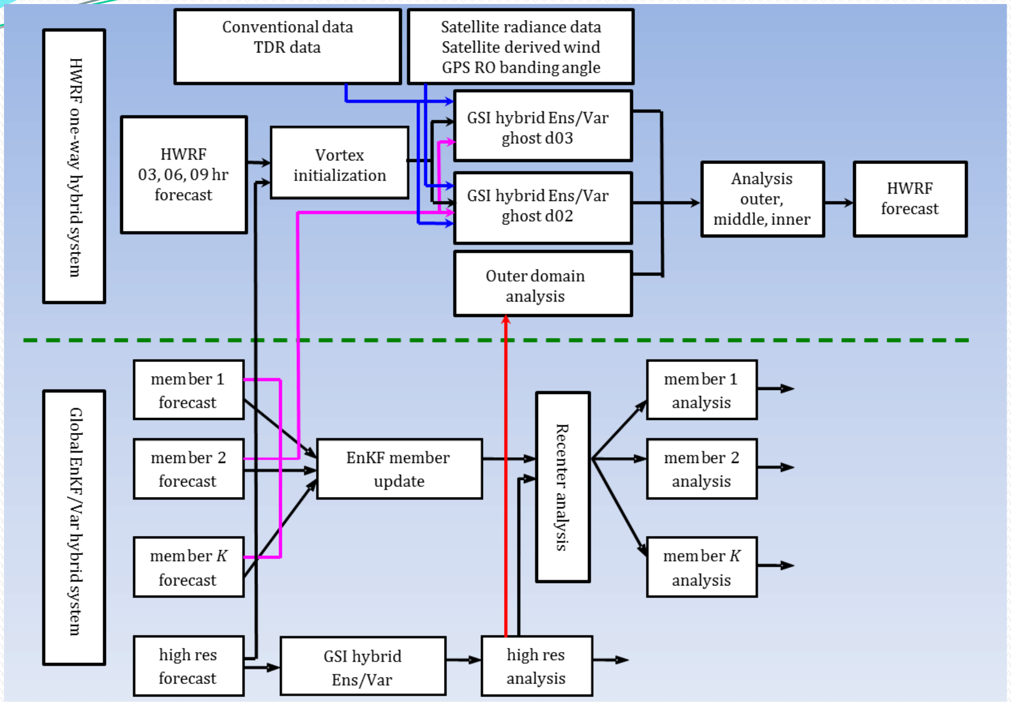


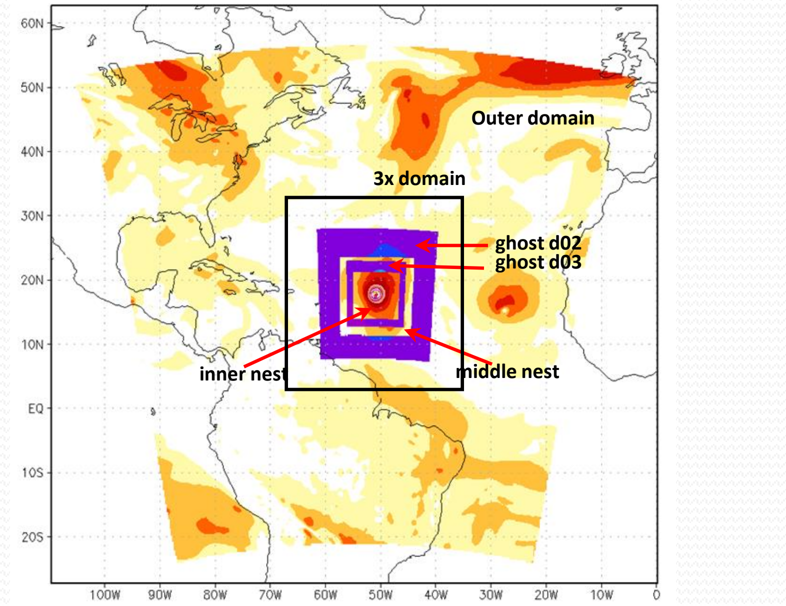
2013 initialization



Proposed upgraded init.

HDAS Upgrades for 2014 Implementation





- Data assimilation performed on ghost d02 (20°x20°, 9km) and ghost d03 (10°x10°, 3km) after vortex initialization. GFS analysis is used in outer domain. No DA for outer domain.
- GSI hybrid analysis using global EnKF 80 ensemble member.
- First guess:
  - TC environment cold start from GDAS forecast
  - TC vortex cycled from HWRF forecast
  - First Guess at Appropriate Time (FGAT)
- Observational data:
  - ghost d02: conventional data (including dropsonde data), TDR data and Satellite Data
  - ghost d03: conventional data (including dropsonde data) and TDR data (no satellite data for 3km analysis)

Satellite radiance assimilation for 9km (ghost_d02) domain:

- use GFS-HWRF blended vertical coordinate (75 levels)
- use bias correction estimations from global analysis
- use GFS ozone profiles

Satellite Data:

Radiances from IR instruments (HIRS,AIRS, IASI, GOES Sounders), Radiances from MW instruments (AMSU-A, MHS, ATMS), Satellite derived wind, GPS RO bending angle

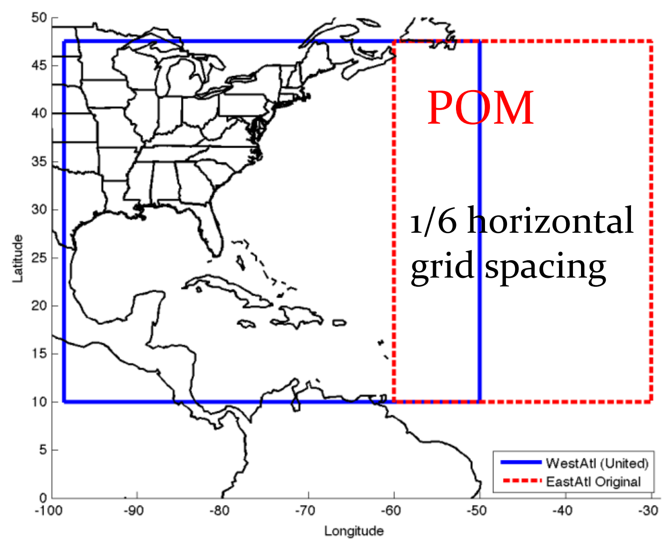
Data assimilation upgrades

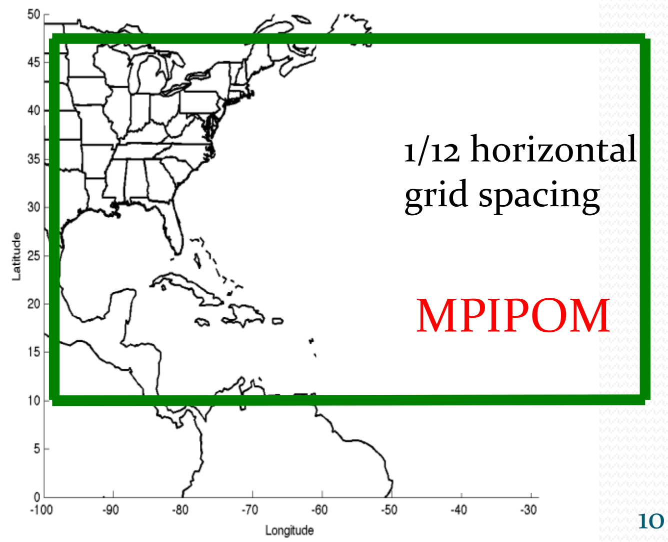
1. Apply regional hybrid GSI analysis for both D2 (9km) and ghost (3km) domains
2. Assimilate the conventional data and TDR, GSPRO, satellite derived wind, brightness temperature from IR instruments (HIRS, AIRS, IASI, GOES Sounder) and MW instruments (AMSU-A, MHS, ATMS)
3. Set satellite thinning box to 90 KM for IR instruments, and 45 KM for MW instruments
4. Change 3-hourly FGAT to hourly FGAT – provide more accurate first guess fields, especially for fast moving and developing storms
5. Further refinements in TDR data assimilation including advanced thinning strategies and removal of surface pressure flag (include it in assimilation); add dropsonde data in the inner core when available (especially temperature and moisture data).

domains	D01 (27km)	ghost_d02 (9km)	ghost_d03 (3km)
T14C	Using GFS analysis	20°x20°	10°x10°
		Conventional, satellite radiance, satellite wind, GPS RO, TDR	Conventional and TDR

Ocean Upgrades: MPI POM and MPI Coupler

1. **MPIPOM-TC uses MPI software framework for running on multiple processors, allowing for both higher resolution and larger domain sizes;**
2. **Unified domains for NATL basin;**
3. **For the first time, 3D Ocean for EPAC basin;**
4. **For 2014 hurricane season, both HWRF and GFDL models will have the same feature based ocean initialization for Atlantic and GDEM based initialization for Easter Pac**
5. **Upgraded coupler with multi-processor capability and advanced interpolation/ extrapolation techniques**
6. **Additional products for real-time ocean diagnostics**





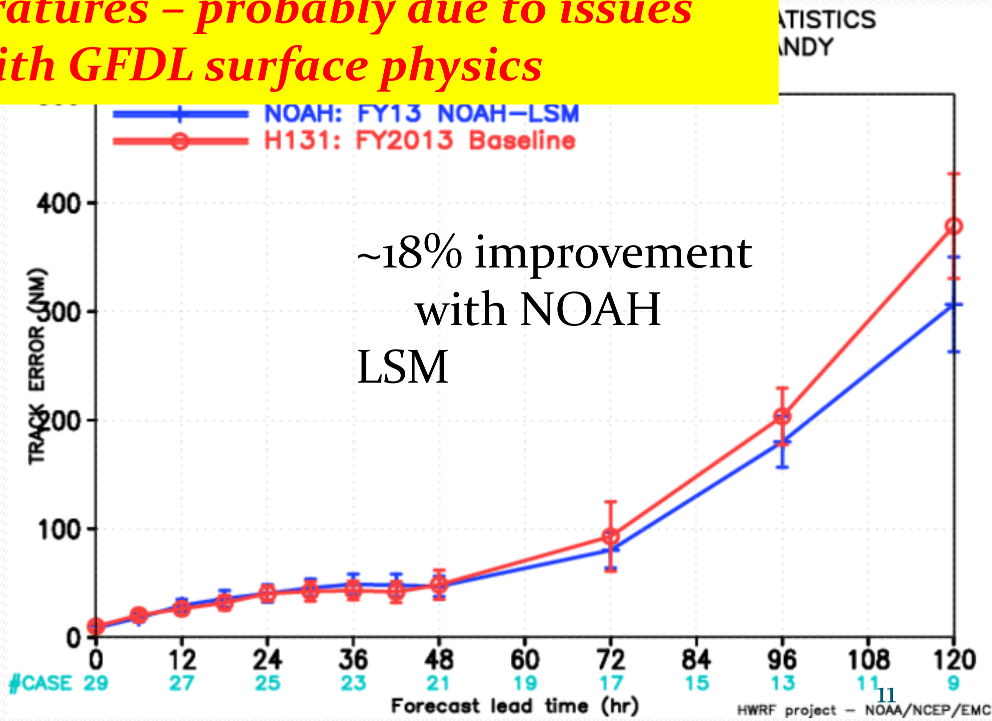
Upgraded Land Surface model (GFDL slab to NOAH LSM)

1. GFDL slab has shown large negative temperature bias over SW CONUS
2. NOAH LSM significantly reduced the negative temperature bias
3. HWRF will include additional products for down-stream applications (e.g. storm surge, inland flooding)
4. Track errors of land-falling storms seem to be improved according to pr

Withdrawn from 2014 HWRF upgrades – model crashes with abnormal land surface temperatures – probably due to issues related to coupling the LSM with GFDL surface physics

Previous diagnostic studies showed significant cold bias in surface temperatures over land (c.f. Ligia et al.)

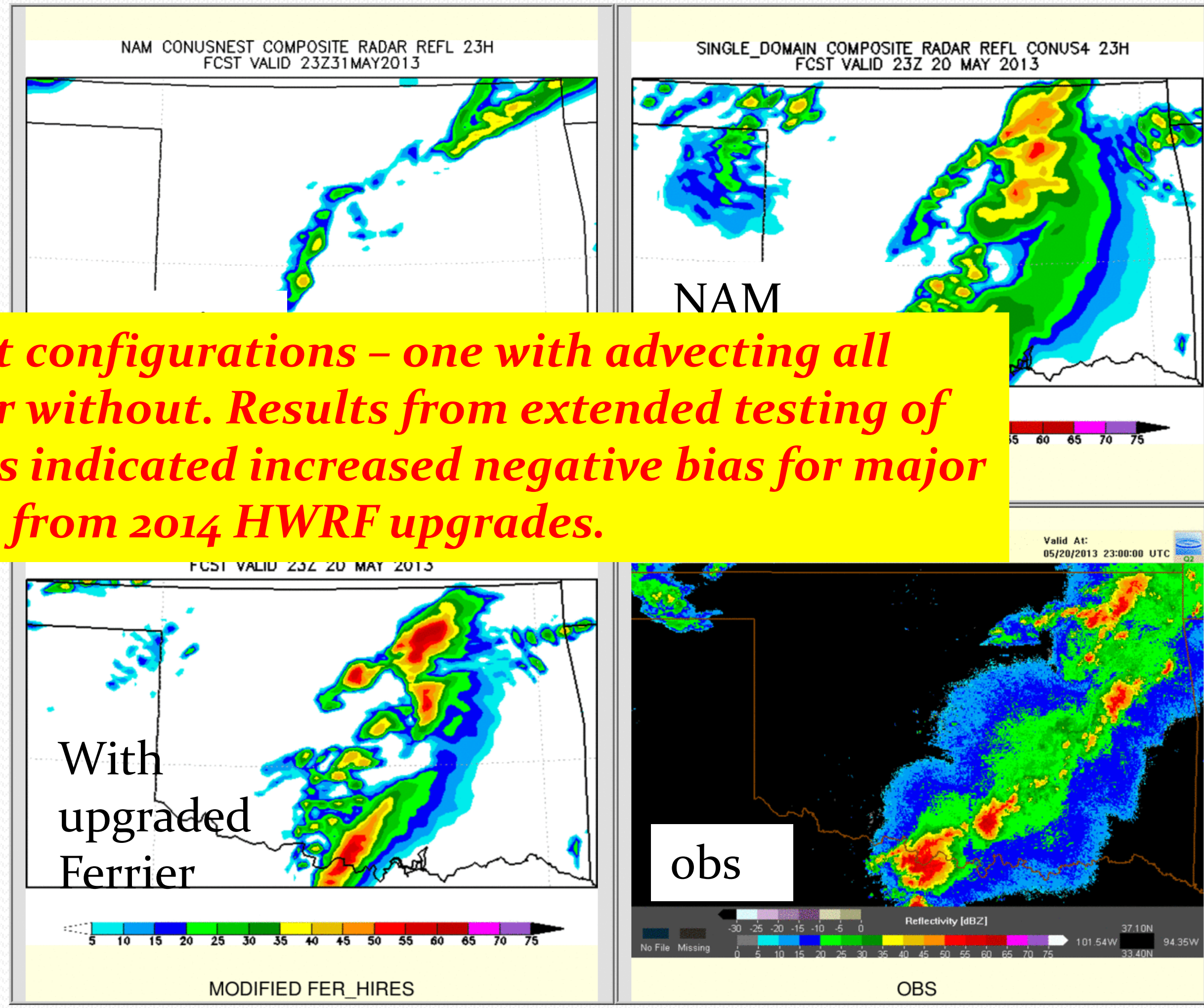
How to estimate and evaluate the impacts of land-radiation-PBL-microphysics interactions?



Upgraded Hi-Res Ferrier Microphysics

1. New ice nucleation scheme to reduce no. concentration of small ice crystals
2. New, simpler closure for diagnosing small ice crystal … precipi… from ic…
3. Advect… species … weighted rime factor (i.e. "graupel")
4. Slightly slower fall speeds of rimed ice
5. Increase the maximum (minimum) number concentration of small (large) ice in order to simulate better anvil cloud

Tested two different configurations – one with advecting all species and another without. Results from extended testing of both configurations indicated increased negative bias for major storms. Withdrawn from 2014 HWRF upgrades.

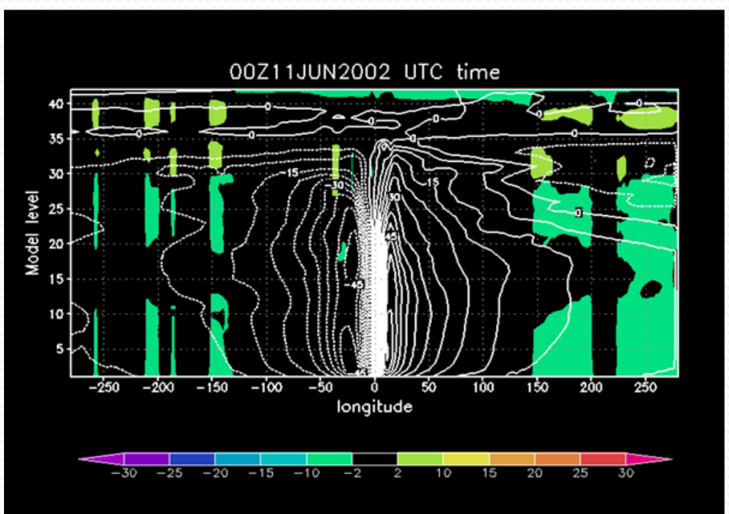


Upgraded SW/LW radiation schemes (GFDL radiation to RRTMG)

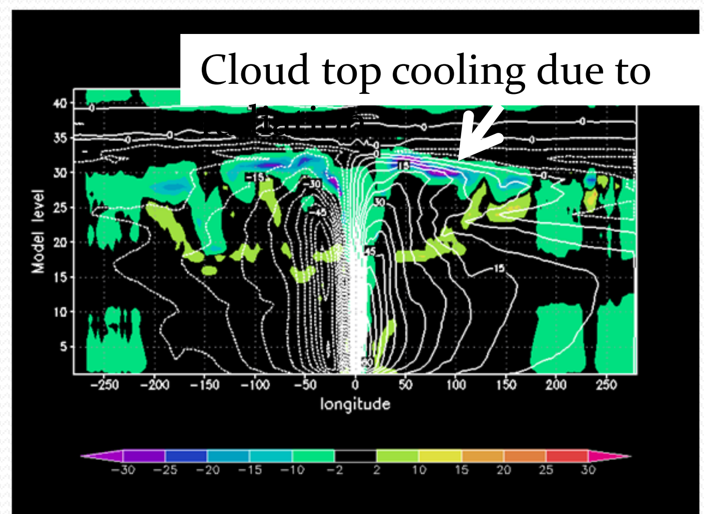
1. GFDL radiation schemes have problems of proper representations of cloud-radiation interactions, especially net cloud top cooling and net cloud base warming.
2. Although the use of RRTMG radiations degraded the intensity forecast

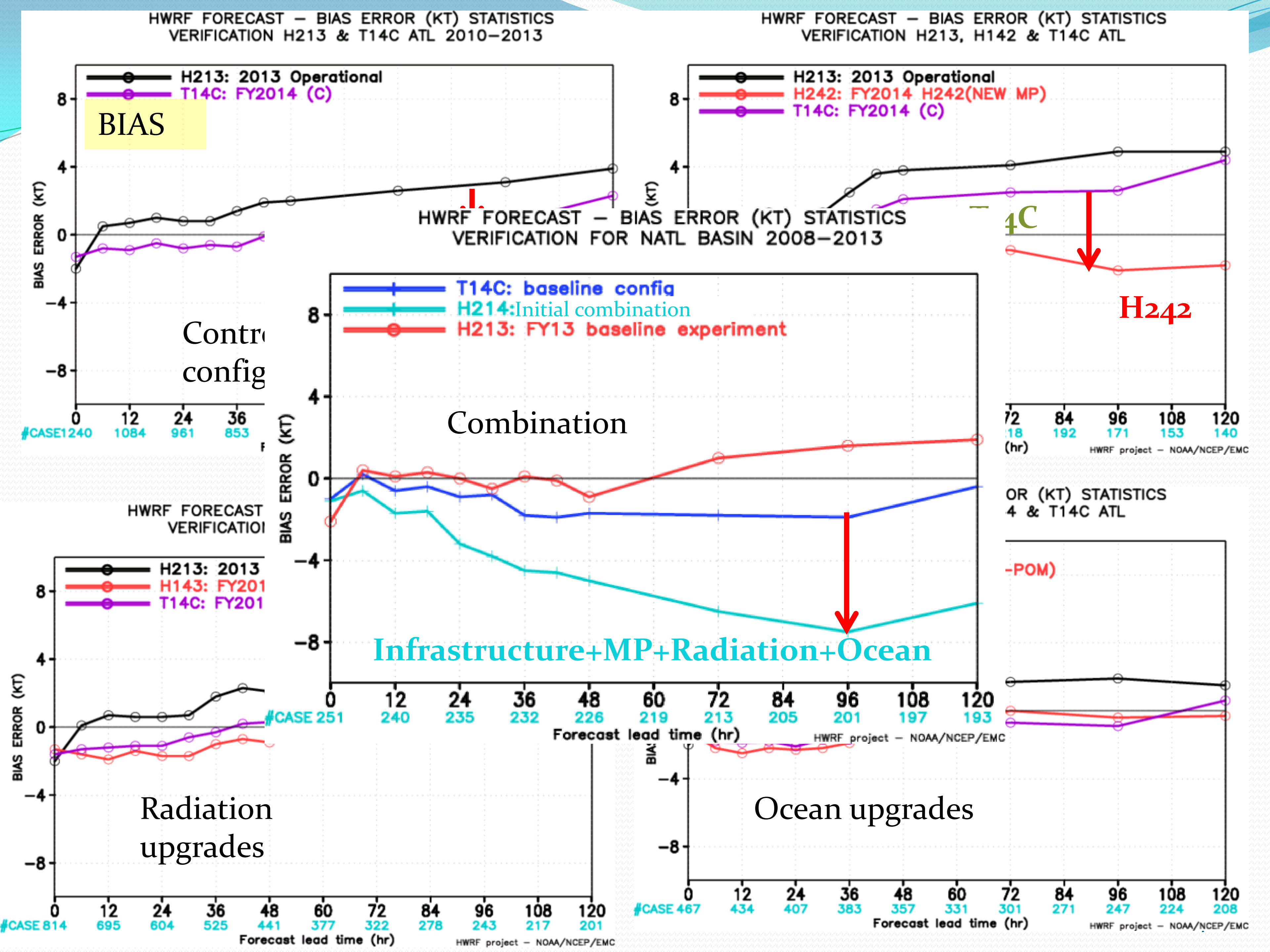
Extended testing of RRTMG (with Microphysics changes) indicated increased negative bias for major storms. Withdrawn from 2014 HWRF upgrades.

HWRF radiation package



RRTMG radiation package




HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION H213 & T14C ATL 2010–2013
H213: 2013 Operational
T14C: FY2014 (C)
BIAS
Contr
config
BIAS ERROR (KT)
#CASE 1240 1084 961 853
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION H213, H142 & T14C ATL
H213: 2013 Operational
H242: FY2014 H242(NEW MP)
T14C: FY2014 (C)
H242
HWRF project – NOAA/NCEP/EMC
HWRF FORECAST – BIAS ERROR (KT) STATISTICS
VERIFICATION FOR NATL BASIN 2008–2013
T14C: baseline config
H214:Initial combination
H213: FY13 baseline experiment
Combination
Infrastructure+MP+Radiation+Ocean
BIAS ERROR (KT)
#CASE 251 240 235 232 226 219 213 205 201 197 193
Forecast lead time (hr)
HWRF project – NOAA/NCEP/EMC
HWRF FORECAST
VERIFICATIO
H213: 2013
H143: FY201
T14C: FY201
Radiation
upgrades
#CASE 814 695 604 525 441 377 322 278 243 217 201
Forecast lead time (hr)
HWRF project – NOAA/NCEP/EMC
OR (KT) STATISTICS
4 & T14C ATL
-POM)
Ocean upgrades
#CASE 467 434 407 383 357 331 301 271 247 224 208
Forecast lead time (hr)
HWRF project – NOAA/NCEP/EMC

Nest Motion and Diagnostics

1. Corrected errors in smoothing parameters – should reduce nest jitter.
2. Changing nest motion frequency from 9 minutes to 3 minutes for inner domain. Will help with fast moving storms (ie.: Maria, Harvey)
3. Adding diagnostic output every nest motion timestep. Will include tracker-based storm location and intensity and tornadic potential related products in support of SPC.
4. Produce better storm total rainfall and maximum wind swaths
5. Add additional diagnostic parameters (SST, thermodynamics, etc.)

Python Rewrite (EMC/DTC Collaboration)

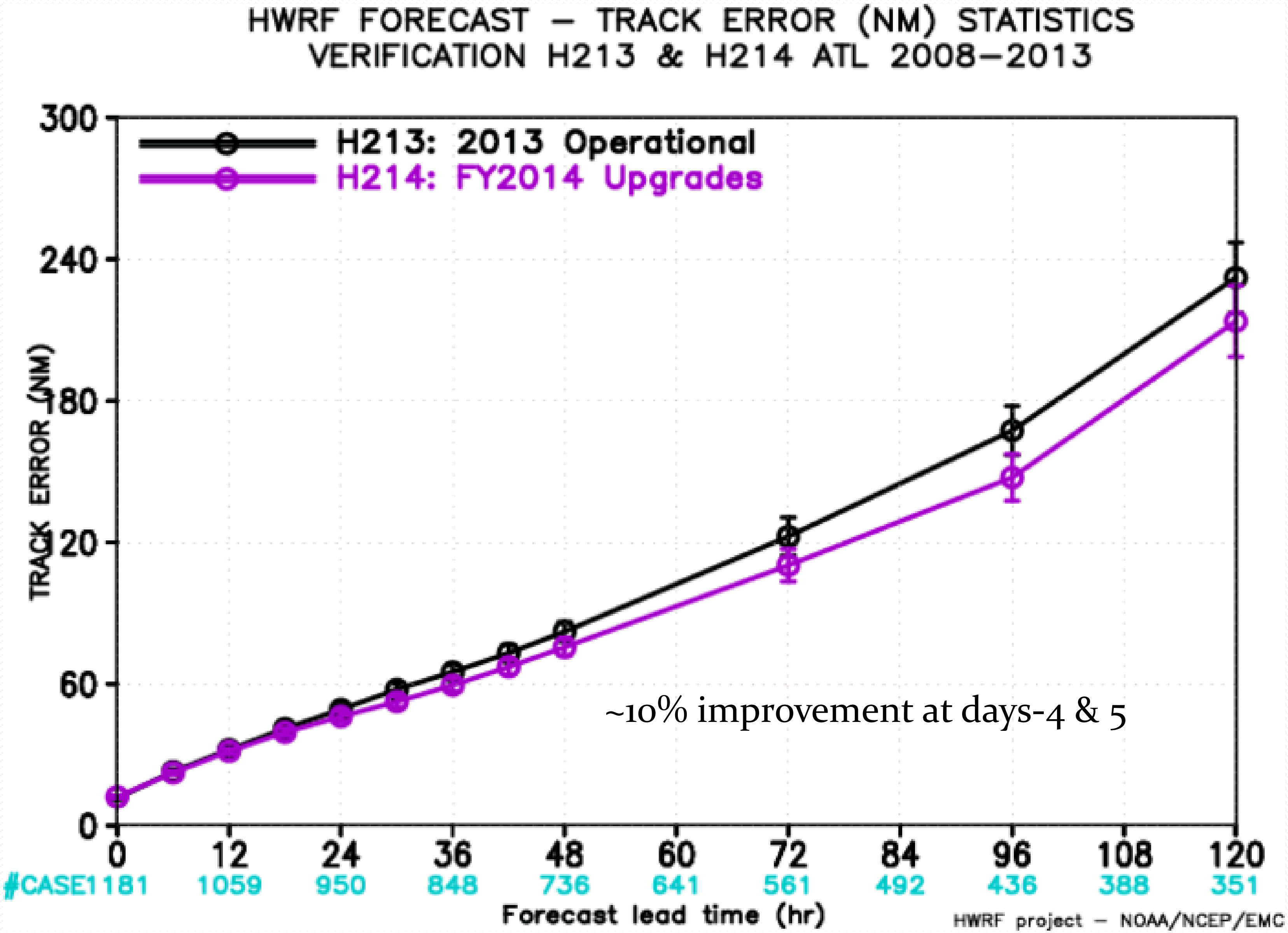
1. Rewrite HWRF scripting system (ush and scripts layers) in Python
2. Reduce code complexity, improve reliability and portability
3. Reduce footprint of HWRF scripts in operations from 50000 lines to about 10000 lines (***only a few major parts of the HWRF system including post-processing were rewritten in python, DTC contributions did not make it on time to include in the final HWRF configuration)***
4. Maintain same scripting system across all collaborators and community, reducing R2O costs.
5. Switch to 100% GRIB2 output from HWRF (no GRIB1) ***(incomplete development. Will be deferred to 2015 hurricane season)***

2014 HWRF pre-implementation Test Plan

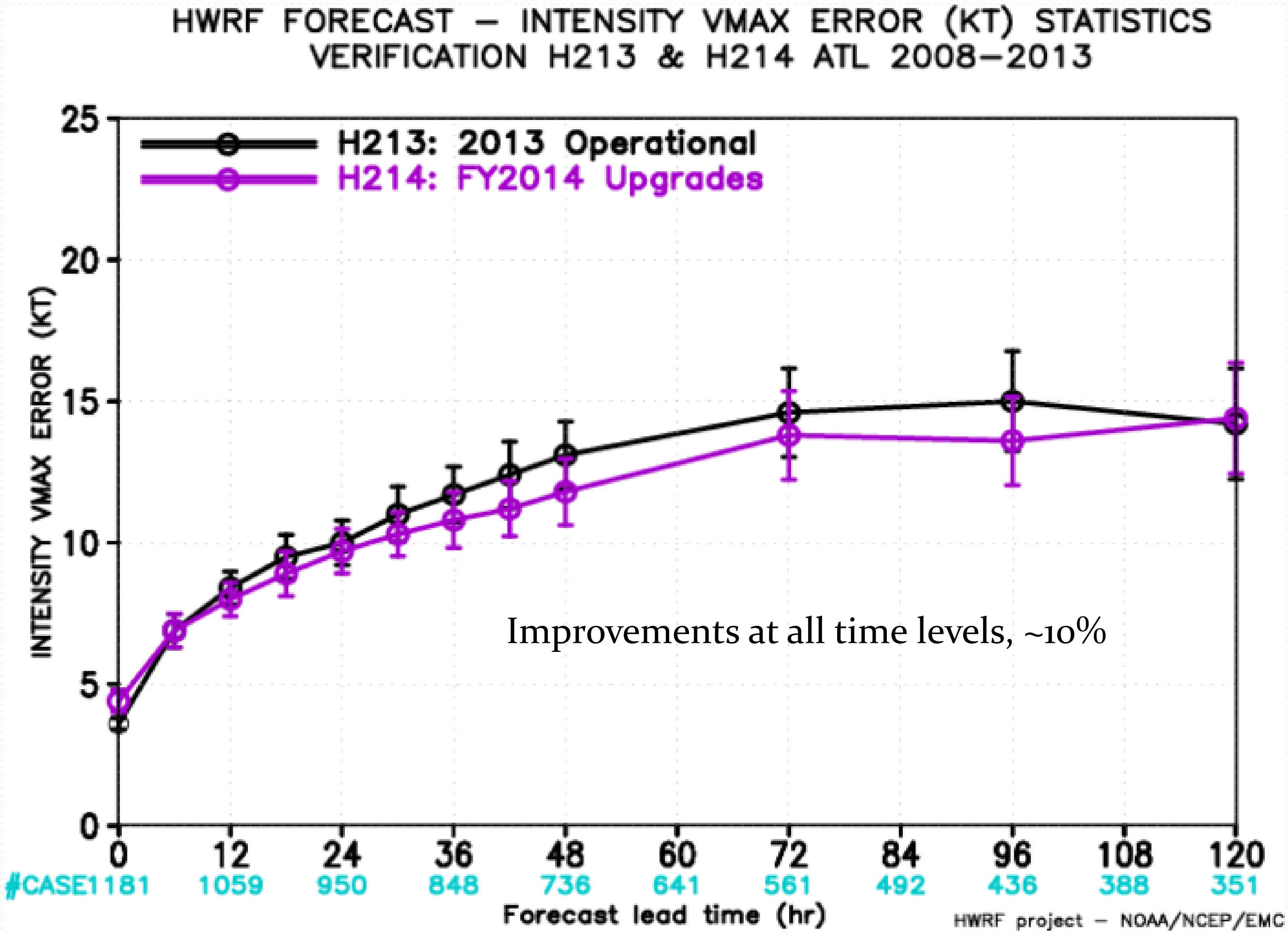
	Infrastructure upgrades	Physics upgrades					Combine
	T14C	Nest motion (H140)	NOAH LSM (H141)	Upgraded Ferrier (H142/H242)	RRTMG (H143)	Ocean (H144)	H214
Descr.	1. Sat Da with more vertical levels 2. Extended d2/d3 3. Upgraded vortex initialization 4. GSI upgrade 5. Invest cycling	New nest motion	NOAH LSM	Separate species, Frime advection with other upgrades (H142) Without advection (H242)	Radiation	MPI-POM with new coupler	Baseline + MPIPOM + new nest motion + Python scripts *need to do test runs with new GFS in WCOSS
Person	All	Sam	Young	Weiguo	Chanh	Zhan/URI	All
Cases	Whole 2011,2012 and 2013 storms 2008, 09, 10 TDR cases	Priority cases	Priority cases	Priority cases	Priority cases	Priority cases	Whole 2011-13 and 2008-10 TDR cases
Due date	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	April 7
Platform	Jet/Zeus	Jet/Zeus	Jet/Zeus	Jet/Zeus	Jet/Zeus	Jet	Jet/WCOSS/Zeus

Systematic evaluation of each component of the upgrades is key for success.
More than 10000 simulations on multiple platforms

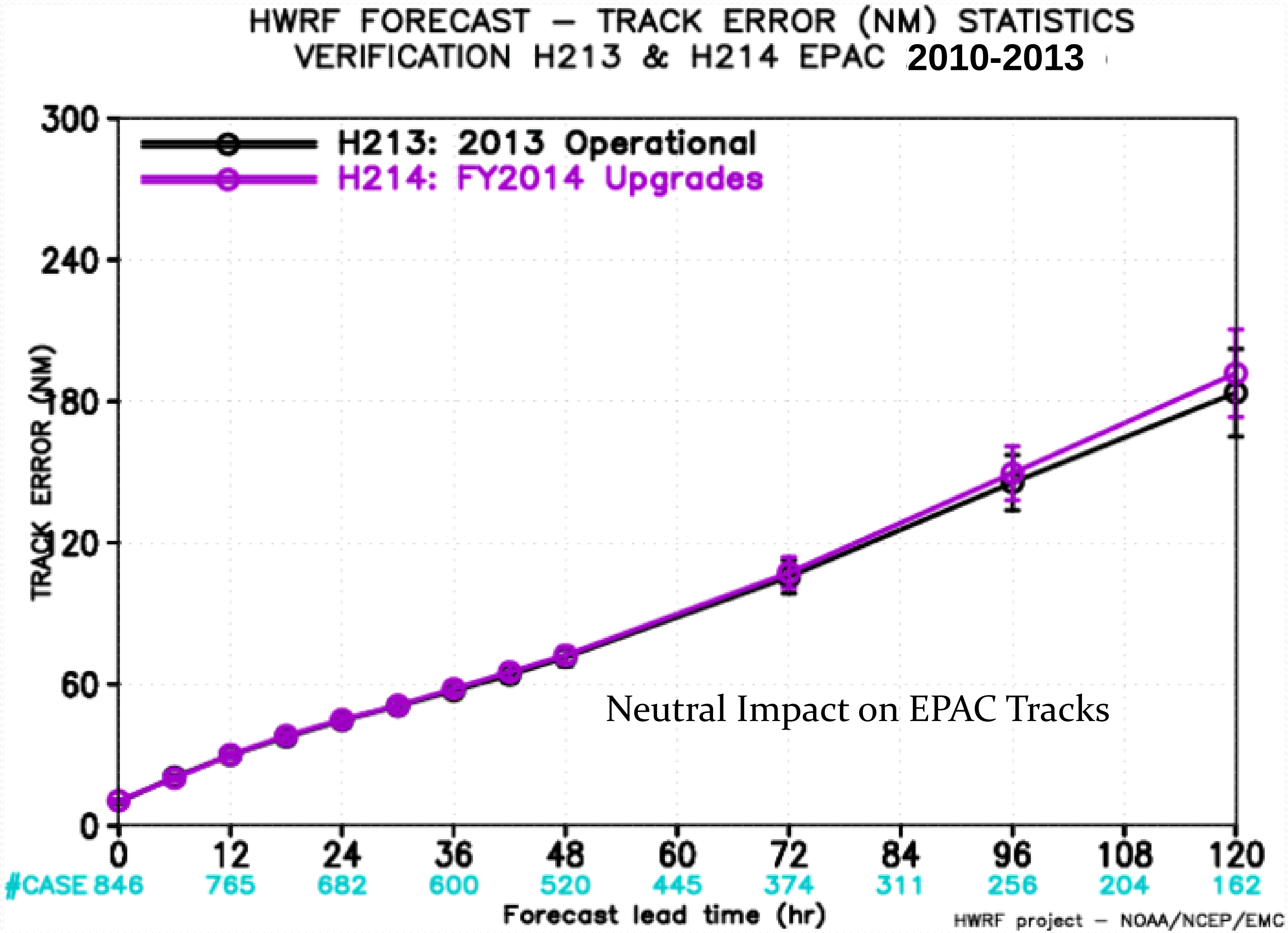
2014 HWRF Final Results: Atlantic Track Errors 2008-2013
Late Model Verification



2014 HWRF Final Results: Atlantic Intensity Errors 2008-2013
Late Model Verification

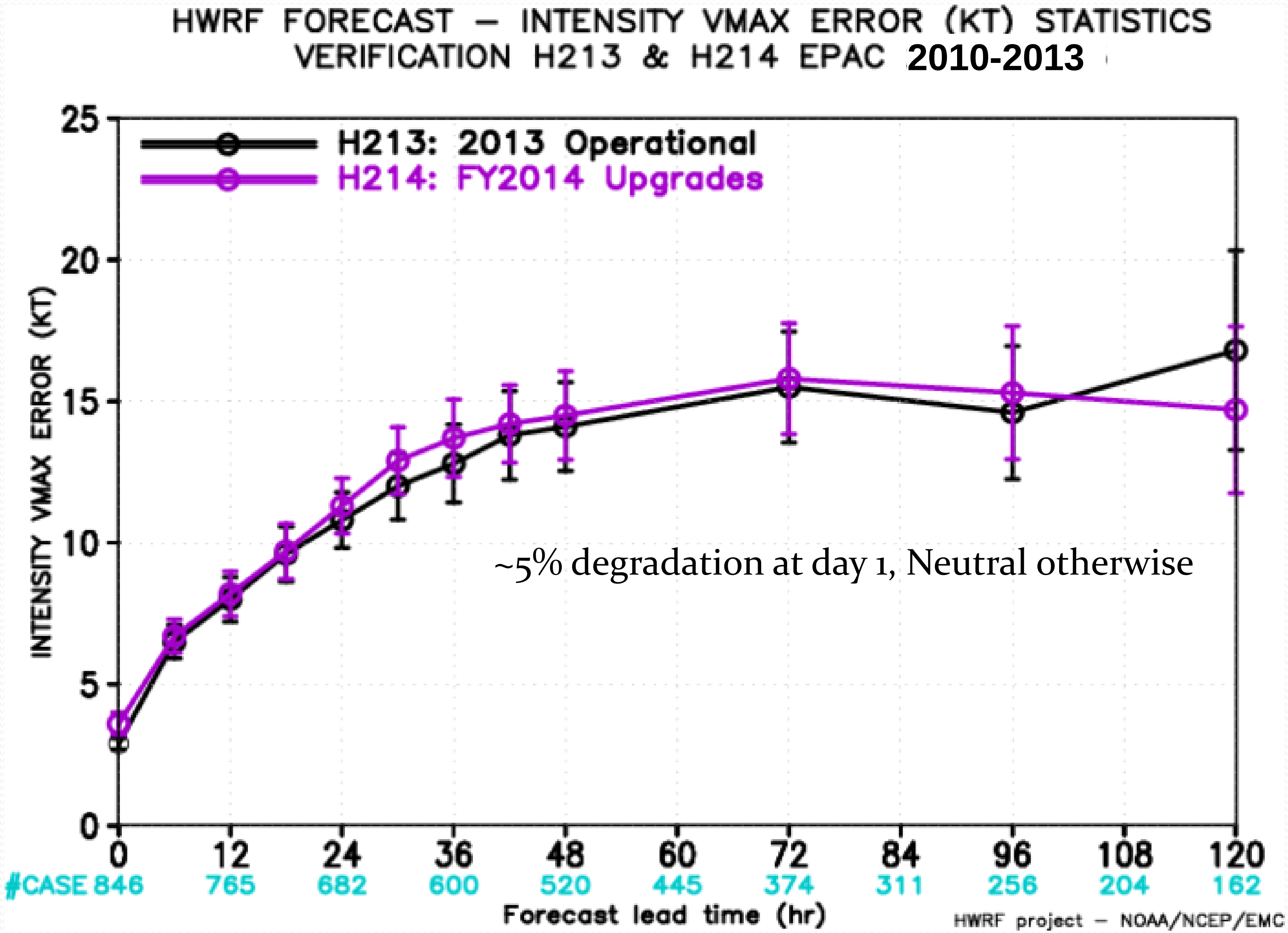


2014 HWRF Final Results: EPAC Track Errors 2010-2013
Late Model Verification

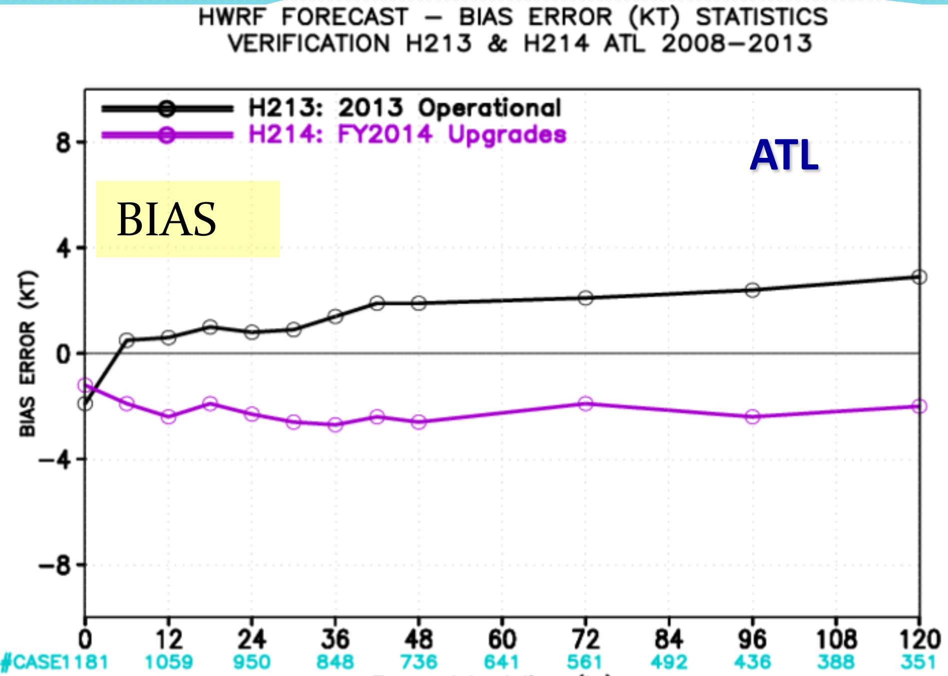


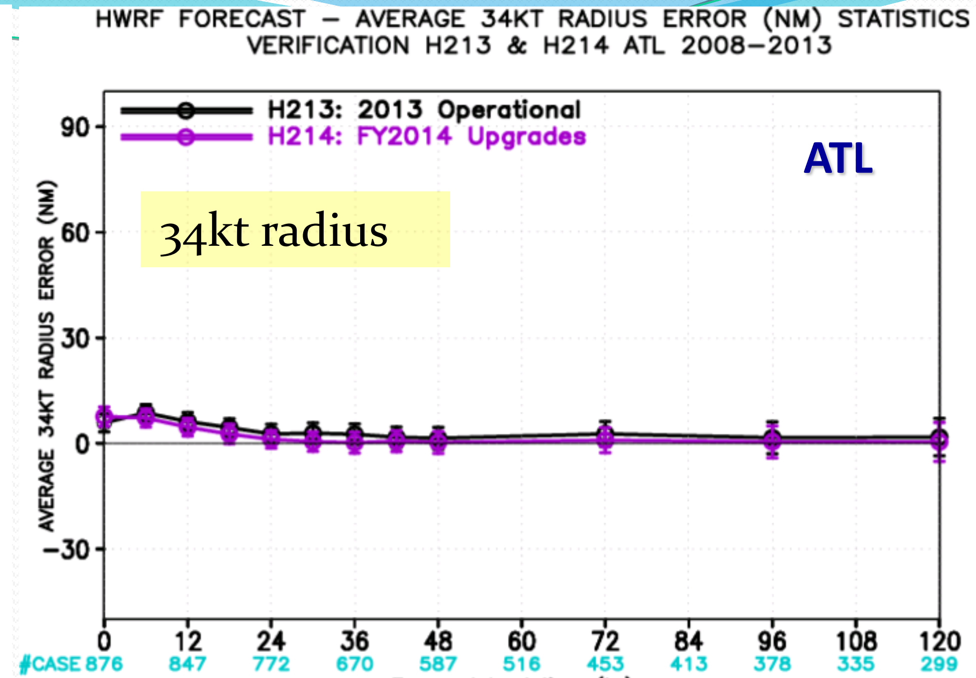
2014 HWRF Final Results: East Pac Intensity Errors 2010-2013

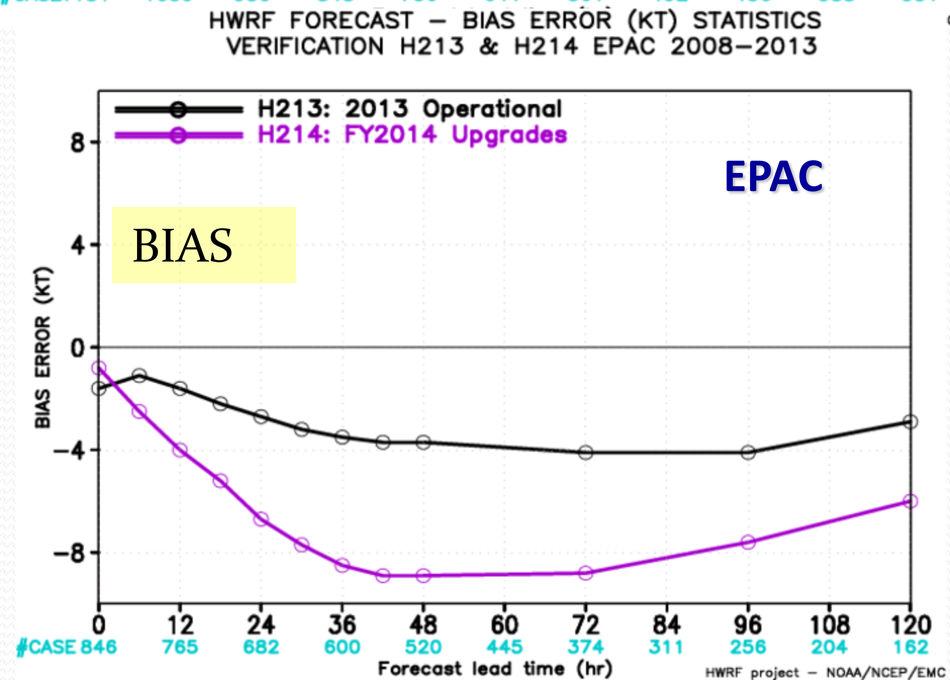
Late Model Verification

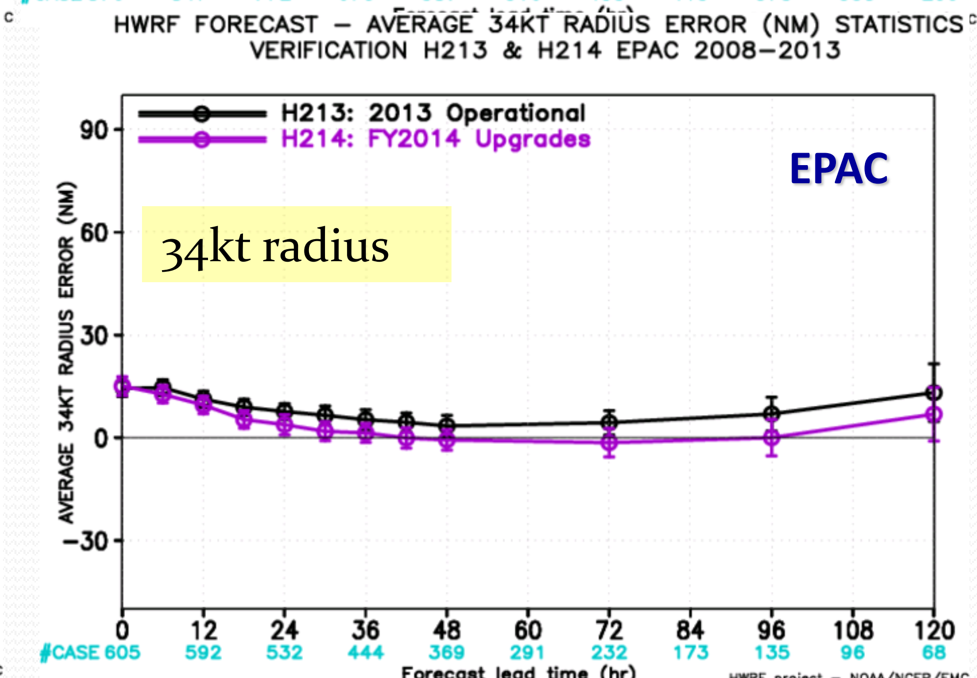


2014 HWRF Final Results: ATL & EPAC Intensity Bias & 34kt Radius

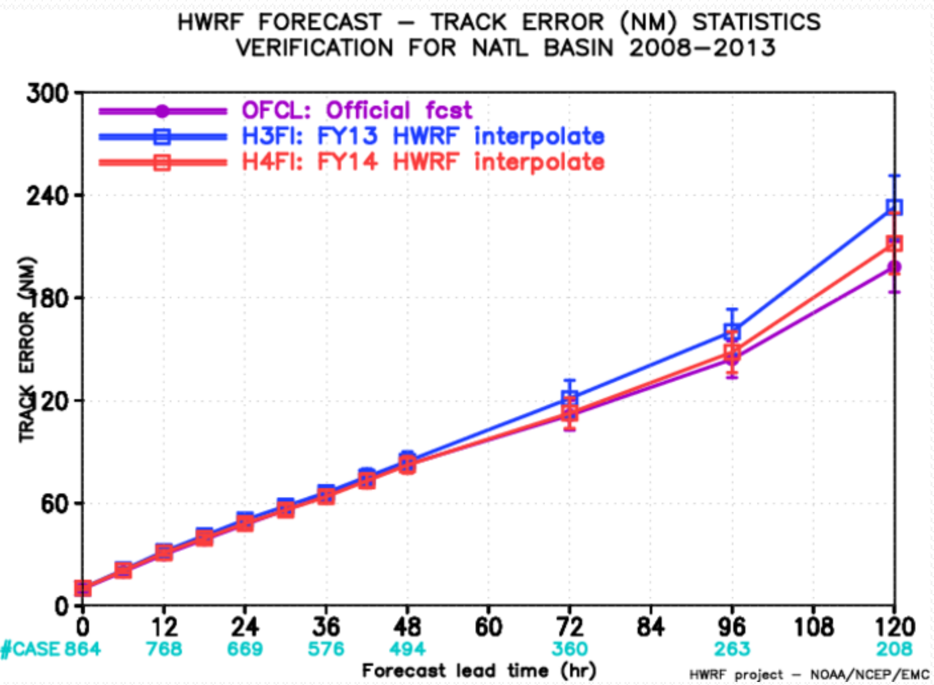


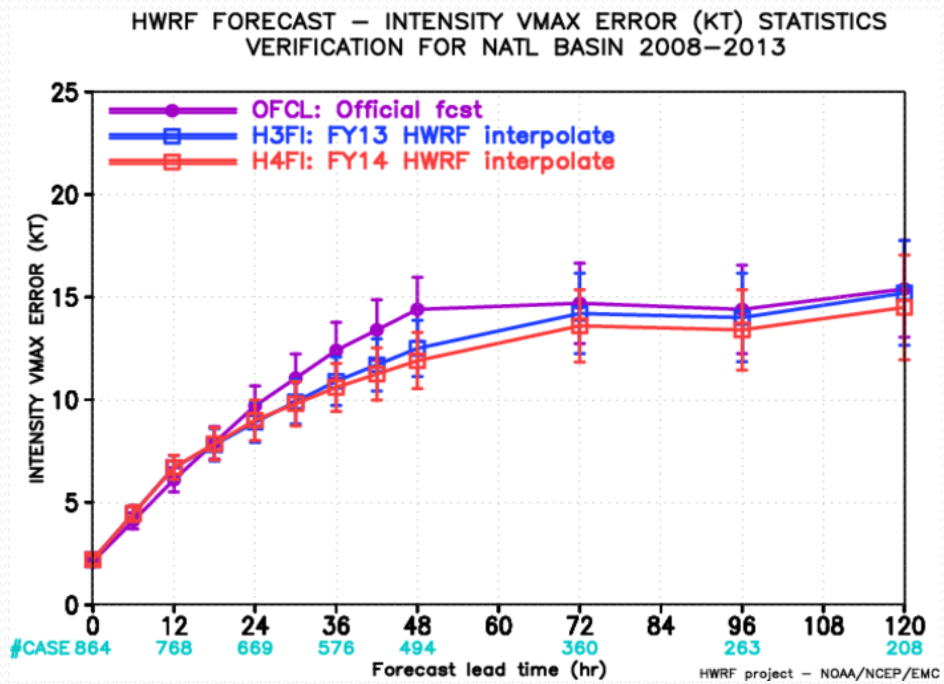






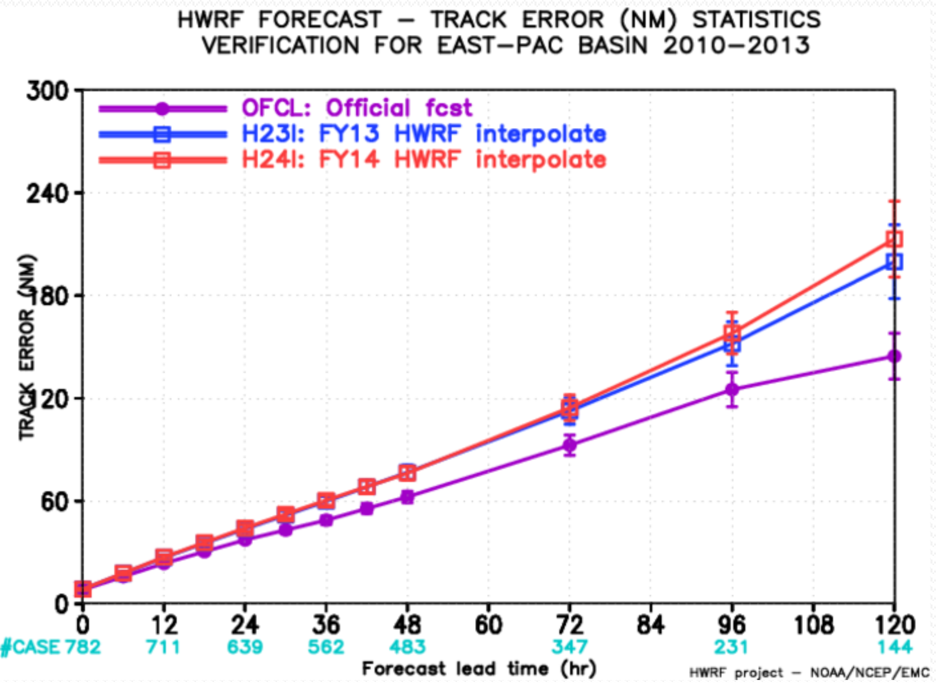
2014 HWRF Final Results: Atlantic Track/Intensity Errors 2008-2013: Early Model Verification

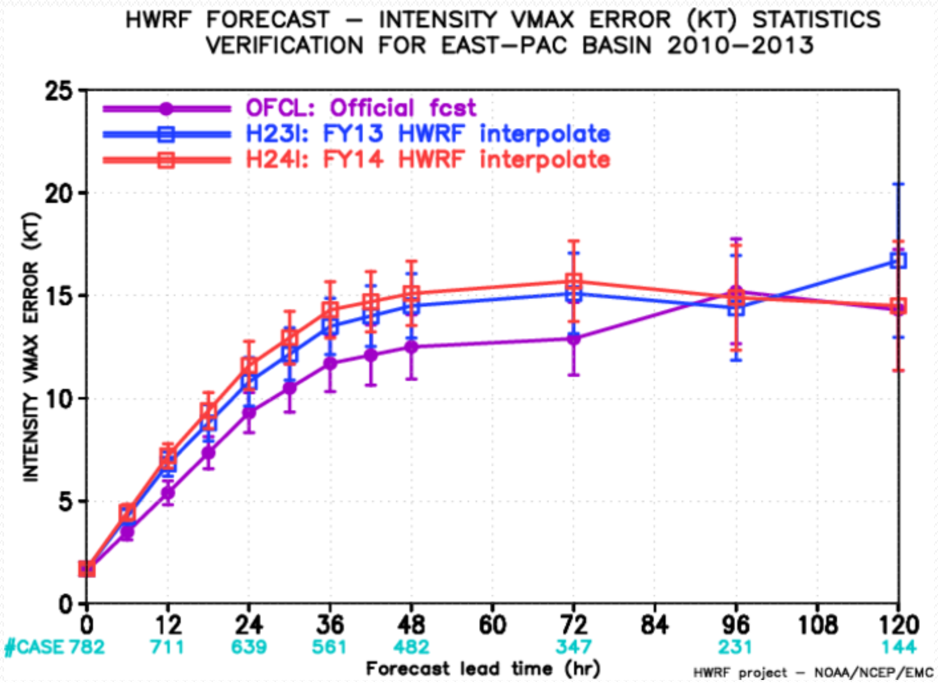




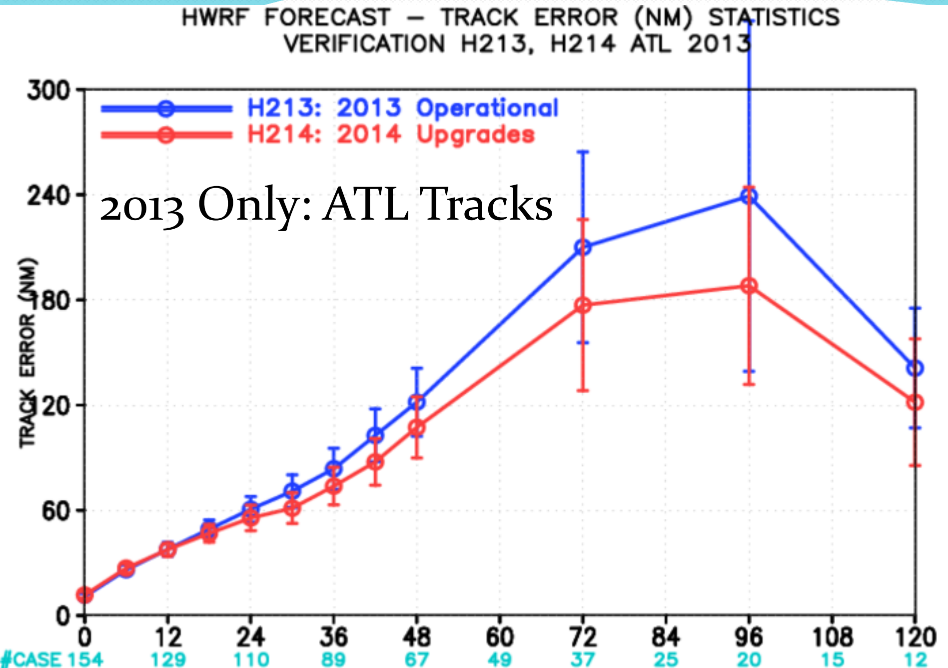
Early Model Verification now shows 2014 HWRF matches the Atlantic track errors from NHC OFCL through 96-hrs and outperforms intensity errors at all times by 10-15%

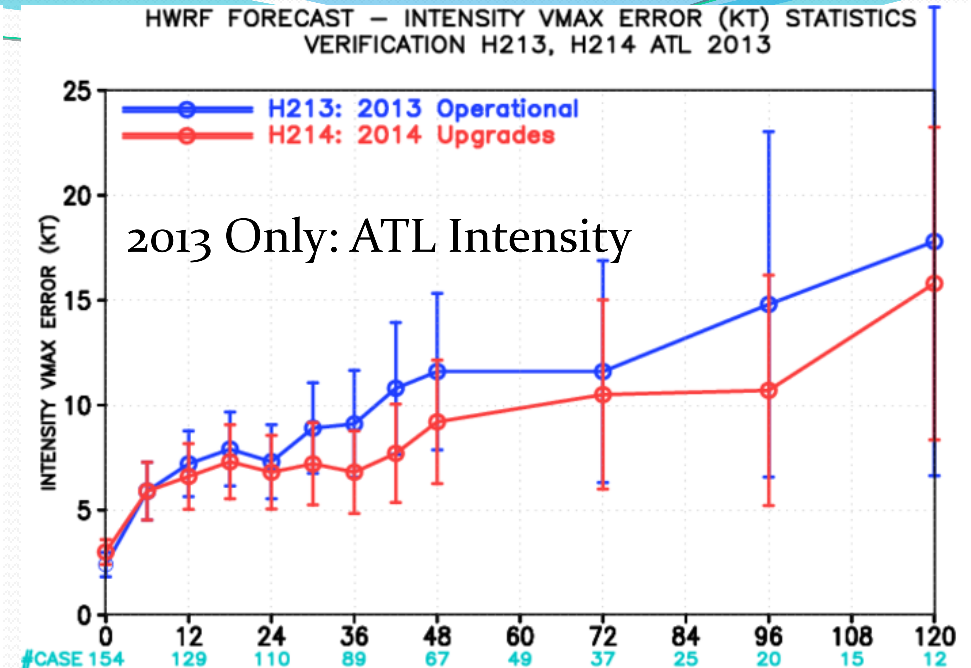
2014 HWRF Final Results: East Pac Track/Intensity Errors 2010-2013: Early Model Verification

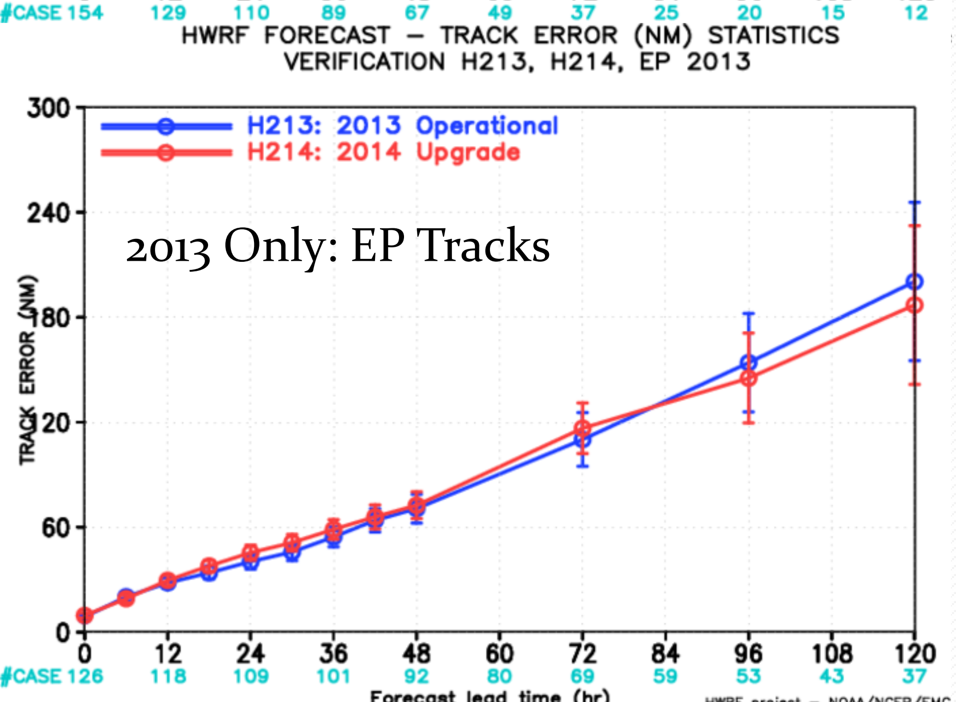


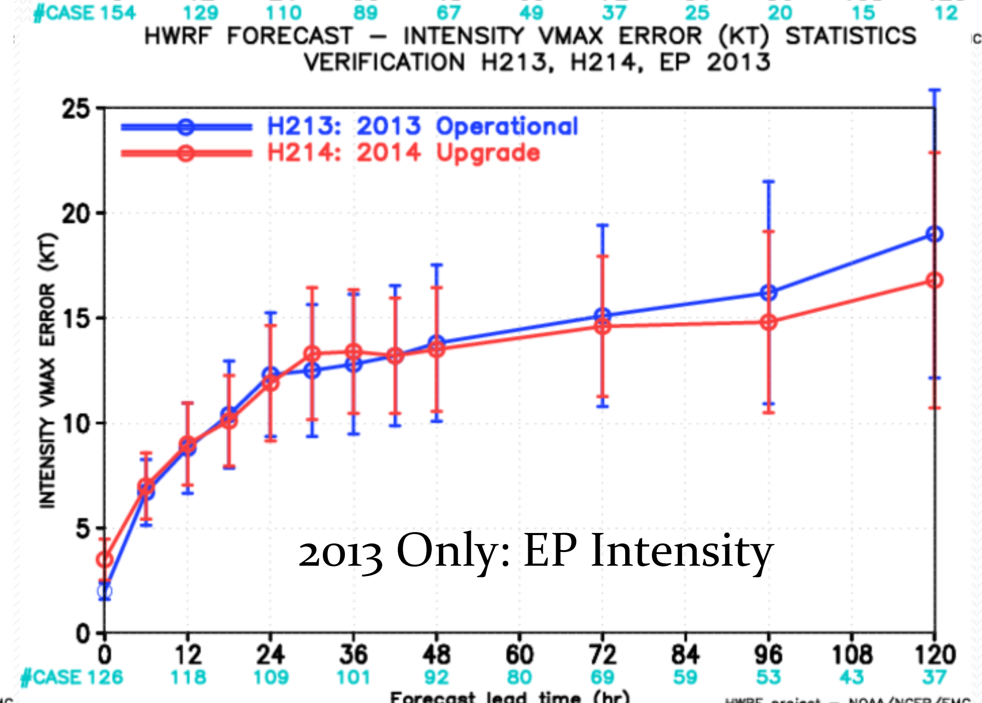


Early Model Verification indicates East Pac track and intensity errors comparable to 2013 HWRF but not as good as the NHC OFCL forecasts

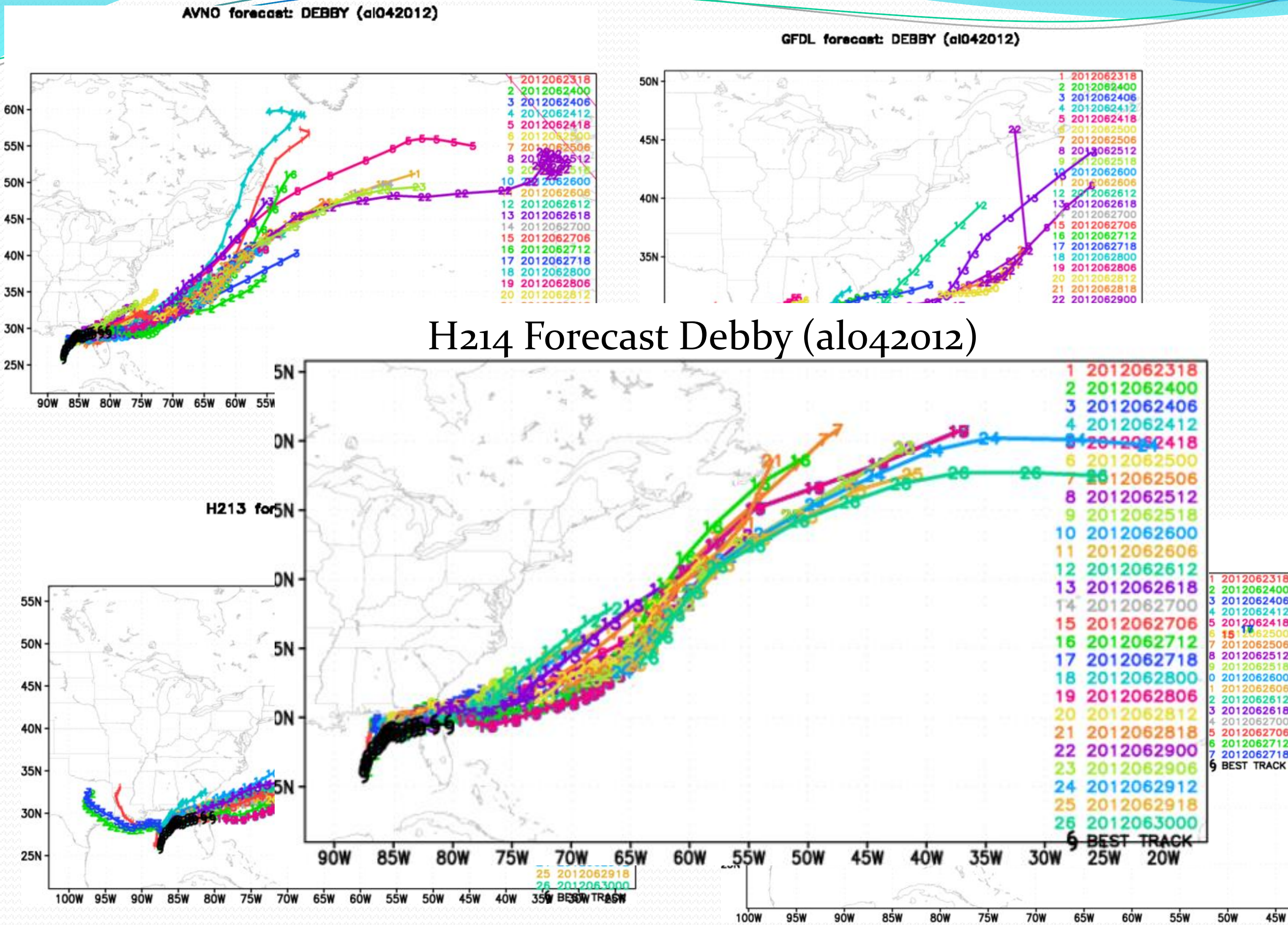

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION H213, H214 ATL 2013
H213: 2013 Operational
H214: 2014 Upgrades
2013 Only: ATL Tracks
TRACK ERROR (NM)
#CASE 154 129 110 89 67 49 37 25 20 15 12


HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION H213, H214 ATL 2013
H213: 2013 Operational
H214: 2014 Upgrades
2013 Only: ATL Intensity
INTENSITY VMAX ERROR (KT)
#CASE 154 129 110 89 67 49 37 25 20 15 12


HWRF FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION H213, H214, EP 2013
H213: 2013 Operational
H214: 2014 Upgrade
2013 Only: EP Tracks
TRACK ERROR (NM)
#CASE 126 118 109 101 92 80 69 59 53 43 37
Forecast lead time (hr)


HWRF FORECAST – INTENSITY VMAX ERROR (KT) STATISTICS
VERIFICATION H213, H214, EP 2013
H213: 2013 Operational
H214: 2014 Upgrade
2013 Only: EP Intensity
INTENSITY VMAX ERROR (KT)
#CASE 126 118 109 101 92 80 69 59 53 43 37
Forecast lead time (hr)

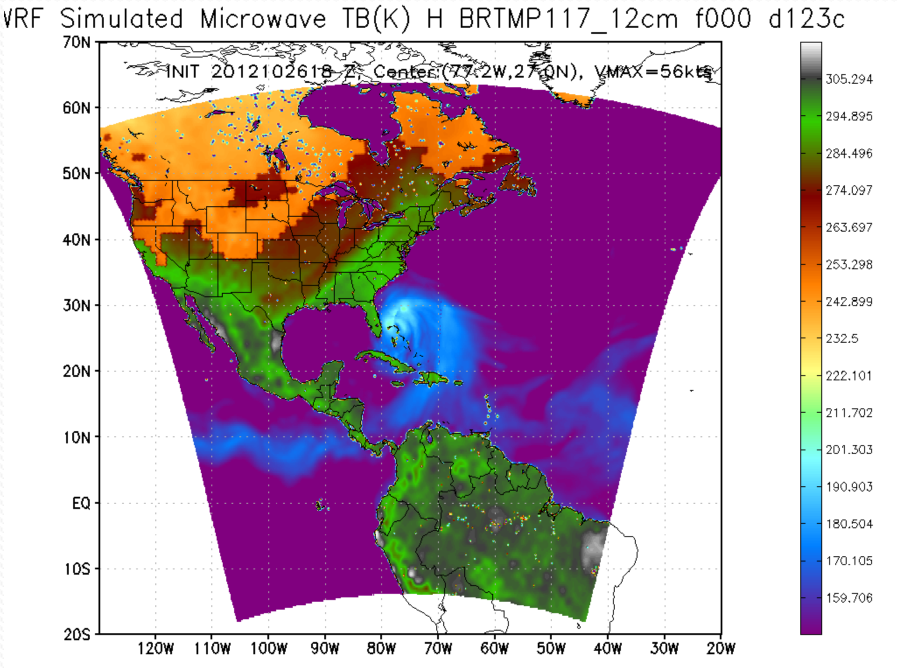
H214 Forecast Debby (al042012)

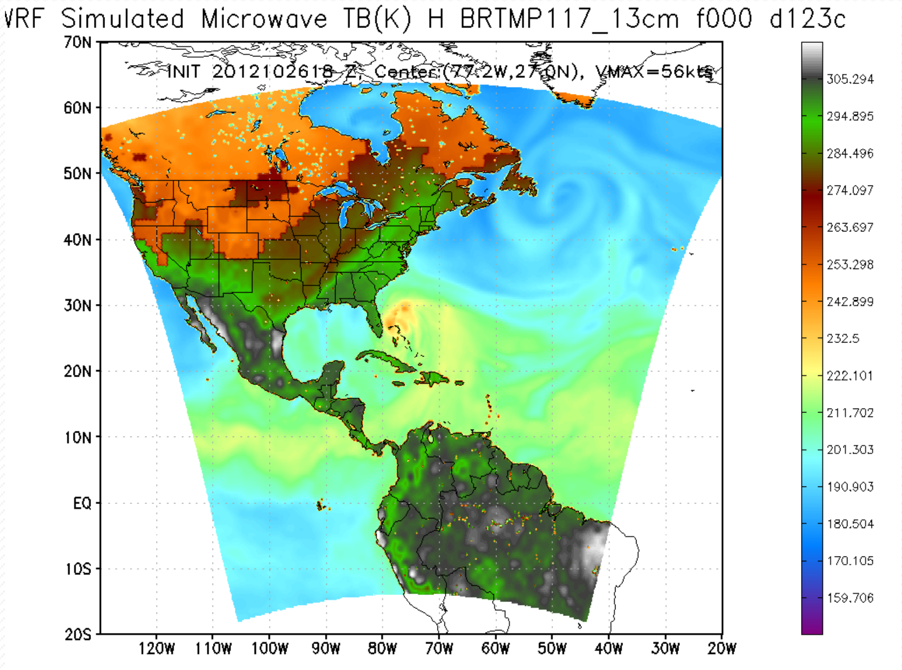


Newly-added products for 2014 Hurricane Season

SSMI/S 19GHz H

SSMI/S 19GHz V

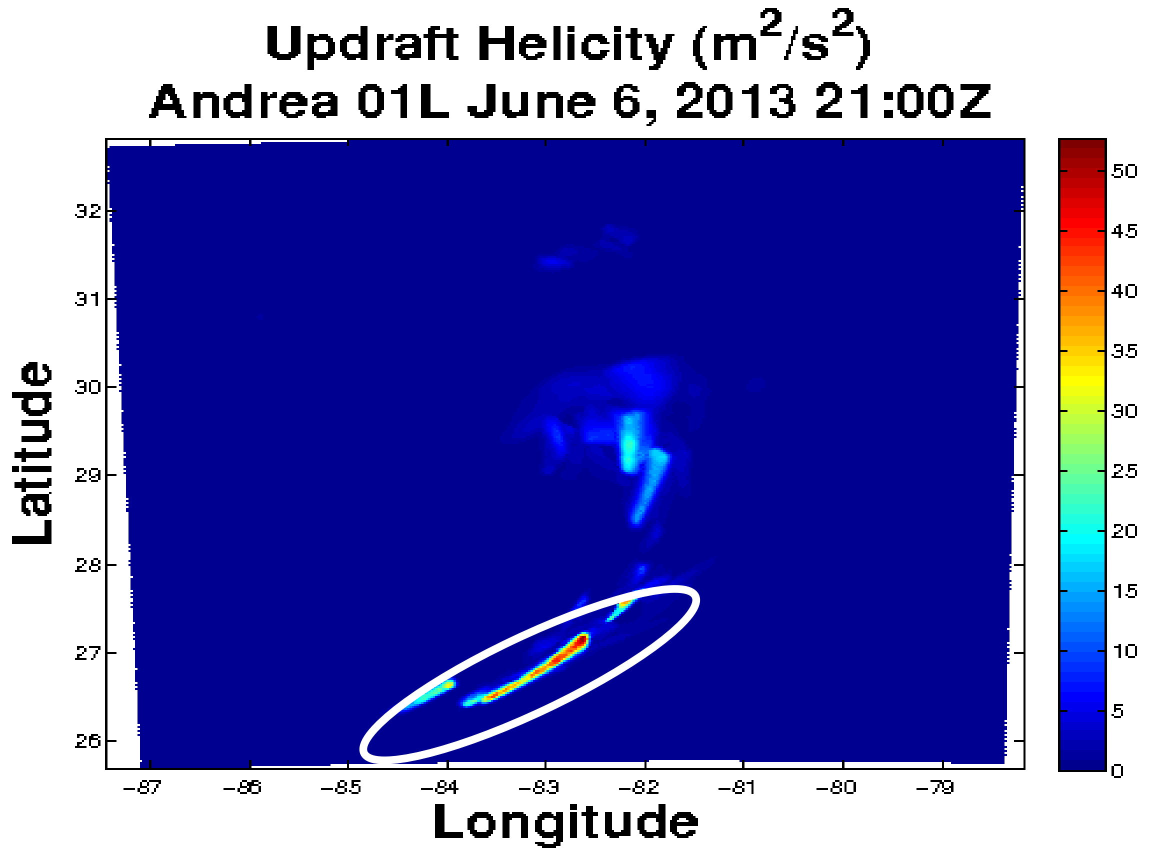




Sandy 18L 2012102618

Newly-added products for 2014 Hurricane Season

Updraft helicity (and tornado genesis potential) fields at the request of SPC



Summary

- Further enhancements suggested for 2014 operational HWRF include
  - Increased vertical resolution (from 43 to 61 levels); Increased model top (from 50 hPa to 2 hPa); Increased nest domain size (20% for 9km; 10% for 3km), coupled to higher resolution (1/12 deg.) MPIPOM-TC with uniform trans-atlantic basin and 3D ocean for Eastern Pacific basin
  - Revised and more advanced vortex initialization including cycling of Invests; Further advancements to one-way hybrid GSI including assimilation of TDR/Dropsonde/Satellite data in the hurricane core and environment
  - Improved nest tracking, advanced diagnostic products and several product enhancements.
- Retrospective testing for 2008-2013 hurricane seasons for Atlantic with FY2014 HWRF configuration (H214) indicated significant enhancements in model forecast skill for track and intensity forecasts for the Atlantic Basin (~10% improvement) compared to the 2013 operational version of the model.
- Neutral impact for the track forecasts for 2010-2013 Eastern Pacific basin hurricane seasons and slight degradation for intensity errors. Results also indicated decreased positive bias for Atlantic and increased negative bias for Eastern Pacific.
- One additional product, a 6min. interval ATCF output, will also be generated along with SPC specific products from the proposed 2014 HWRF configuration.
- NCEP Hurricane Wave Model will become the downstream model for HWRF

Recommendation from NHC for implementing the 2014 HWRF system

The National Hurricane Center (NHC) endorses the implementation of an upgraded HWRF model for 2014. The upgrades to the model include increasing the vertical resolution to 61 levels, expansion of the 2 inner mesh domains, improved initialization including the assimilation of aircraft dropsonde data in the TC inner core, and a unified Atlantic domain for the ocean model. Retrospective runs of the upgraded model for over 1000 cases from the past 6 hurricane seasons show as much as a 10 % improvement in TC track and intensity forecasts for the Atlantic basin. The NHC looks forward to receiving this improved forecast guidance for our operations this upcoming hurricane season.

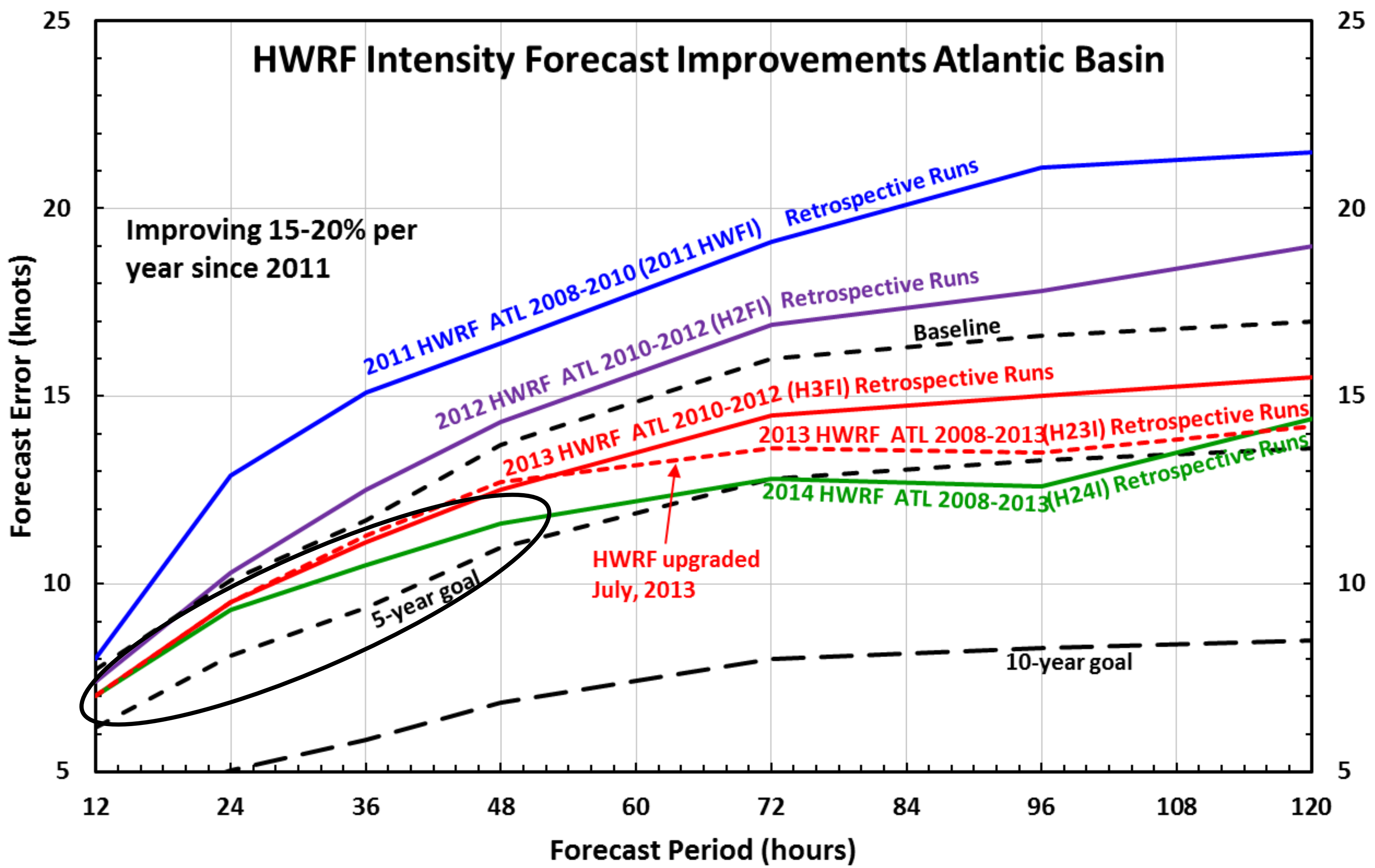
Richard Pasch
Senior Hurricane Specialist
National Hurricane Center

NHC and EMC approved 2014 HWRFV8.0.0 implementation
NCO to implement 2014 HWRF on June 3, 2014

Independent evaluation of results from H214 by Ryan Torn

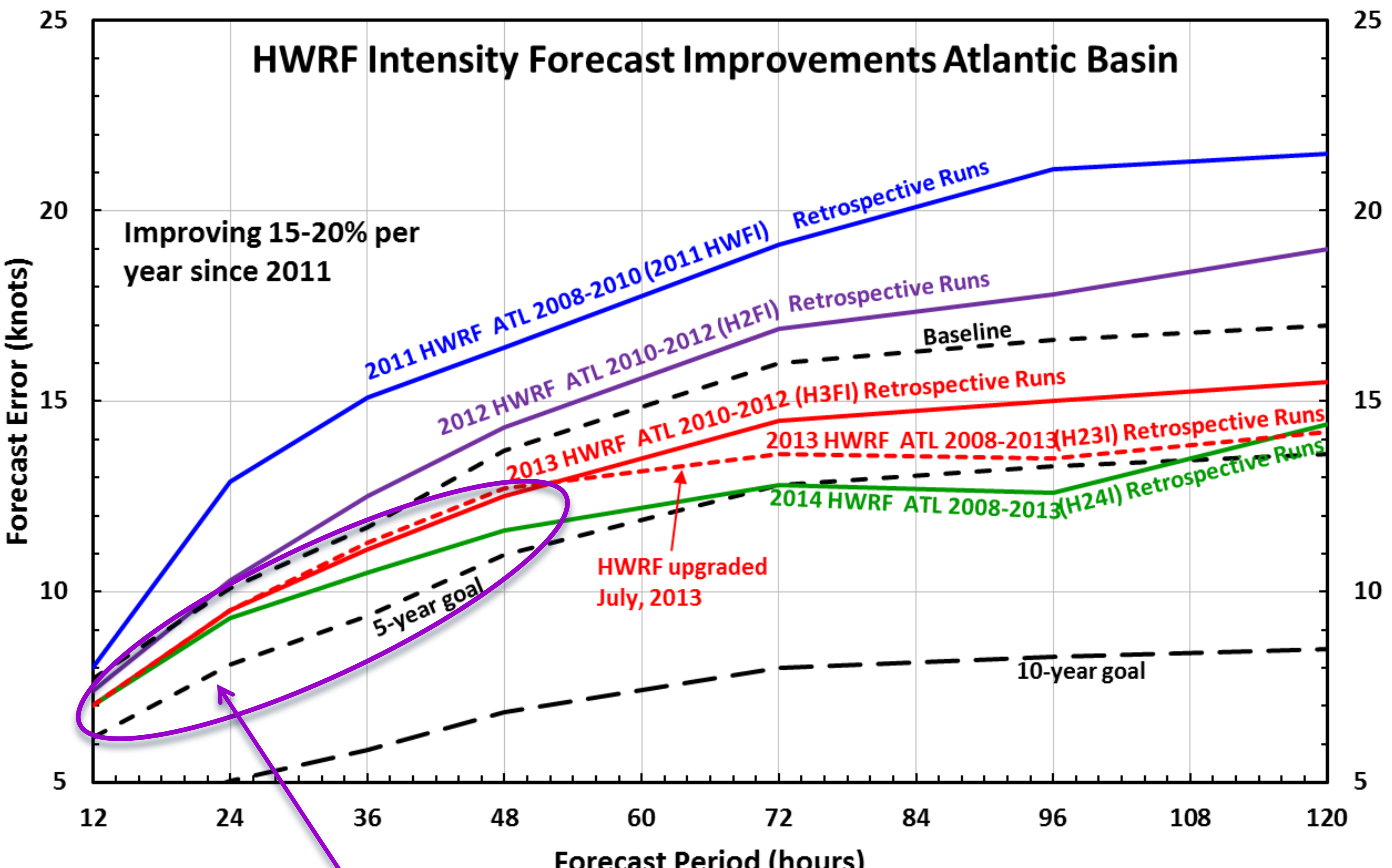
Relative to H213, H214 has:

- Lower position error for weak TCs
- Smaller track biases in eastern and southern parts of basin and for fast-moving TCs
- Lower intensity bias for cold SST and large TCs
- Larger negative intensity biases for EP TCs under “ideal” conditions



HWRF Intensity Forecast Improvements Atlantic Basin
Improving 15-20% per year since 2011
2011 HWRF ATL 2008-2010 (2011 HWFI) Retrospective Runs
2012 HWRF ATL 2010-2012 (H2FI) Retrospective Runs
Baseline
2013 HWRF ATL 2010-2012 (H3FI) Retrospective Runs
2013 HWRF ATL 2008-2013(H23I) Retrospective Runs
2014 HWRF ATL 2008-2013(H24I) Retrospective Runs
HWRF upgraded July, 2013
5-year goal
10-year goal
Forecast Error (knots)
Forecast Period (hours)
25
20
15
10
5
12
24
36
48
60
72
84
96
108
120

Systematic improvements in hurricane intensity forecasts



Focus area for improvements: Much to do with getting more accurate initial vortex structure and environment (where observations and DA are critical)